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THE CHEMICAL COMPOSITION OF SOIL COLLOIDS

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INTRODUCTION

In the past conceptions regarding the chemical composition of soil colloids have been largely based on inference. During the early days of soil investigation it was assumed that the finest particles of the soil, those of colloidal dimensions, were of the same nature as the larger particles, differing only in size. This view, however, did not satisfactorily explain the reactivity with inorganic salts, particularly the property of base exchange. To account for this it was assumed that the finest particles of the soil consisted chiefly of zeolites, which are especially reactive minerals. This view was discarded later when it became evident from mineralogical investigations that definite crystalline zeolites could rarely, if ever, be identified in the soil. It is now coming to be quite generally believed that the inorganic colloidal material of the soil is mainly of a gel-like nature, much like the artificial gels of silica, iron, and alumina.

The earlier conceptions of the composition of soil colloids were for the most part based upon analyses of, or experiments with, the whole soil. An examination of the colloidal material itself is ob-

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viously desirable. The use of a high-power centrifuge has enabled us to isolate from a large number of different soils material exhibiting colloidal properties to a marked degree. It has thus been possible to make chemical analyses of purely colloidal material which has been separated from the noncolloidal part of the soil. These chemical analyses and data based on them are discussed in the following pages.

Under normal conditions very little of the soil colloidal material is present as a sol; practically all of it is present as a gel or as what Freundlich terms "coagel" (*15*, p. 905).[1] Before the colloidal material can be separated from the larger, noncolloidal particles of the soil and analyzed it must be brought into the suspended or sol condition. This bulletin therefore deals almost entirely with the composition of the colloidal material which can be brought into a finely dispersed condition in water without alteration of the discrete noncolloidal particles. It is recognized that there may be present in some soils, besides colloidal material capable of forming a suspension, coarse particles which are colloidal in the sense that opal and coal are colloidal. These materials are not considered here. The soil colloidal material may be considered as essentially a mechanical separate of the soil, similar to the clay fraction, except that the upper size limit of the colloid fraction is smaller than that of the clay fraction. The largest particles in the colloidal material analyzed were apparently less than 0.3 micron in size.

REVIEW OF EARLIER WORK

ULTIMATE CHEMICAL COMPOSITION

Previous knowledge of the chemical composition of the earthy colloidal matter has been contributed by the soil investigator, the geologist, and the workers in the ceramic industries.

Considerable knowledge of the composition of soil colloids can be gotten from the composition of the finest fractions that are obtained in the mechanical analysis of soils. The clay fraction of the American system of mechanical analysis (*14*) may not be entirely colloidal, but it is nearly so, and the "Schlamm" fraction of the European workers is probably nearly all colloidal. Previous work on the composition of these finest mechanical fractions will be considered in detail.

Failyer, Smith, and Wade (*13*) studied the partial composition of the sand, silt, and clay separates and found that the finest soil separates—that is, the more nearly colloidal—were richer in potash, lime, and phosphoric acid than the coarser separates. Loughridge, cited by Hilgard (*22*, p. 385) and Tolman (*44*) have reported some work on the composition of clay separates as determined by digestion in strong acids. In every case they found the clay separates were higher in soluble iron and aluminum than the whole soil.

A few chemical analyses for the total constituents of the finest soil separates obtained by several other investigators are available in the literature.[2] These analyses are given in Table I.

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[1] Reference is made by number (*italic*) to "Literature cited," p. 39.

[2] A number of analyses by acid digestion of fine soil separates of colloidal dimensions are to be found in the literature, but on account of the difficulty of comparing such analyses for the total constituents and also on account of the difficulty of interpreting the figures for the "insoluble residue," the acid digestion analyses are not given in the table.

TABLE 1.—*Chemical composition of the finest separates from certain soils*

Observer	Puchner (*31*)			Schneider (*39*)	Headdon (*21*)	Schloesing (*37*)			Blanck and Preiss (*6*)
Source of fine fraction	Heavy loam soil	Loamy loess soil	Coarse sandy gneiss soil	Residual soil, Washington	Loess soil, Cheyenne, Wyo.	Kaolin from Pieux, France	Kaolin from Talfa, Italy	Kaolin from Manche, France	Heavy clay, Postelberg, Bohemia
Description of fine fraction	Largest particles, 1.5 micron	Largest particles, 1.5 micron	Largest particles, 1.5 micron	Largest particles, 1 micron	Largest particles, 1 micron	Material remaining suspended 34 days	Material remaining suspended 36 days	Material remaining suspended 37 days	Largest particles, 2 microns
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
SiO_2	51.01	50.23	46.54	41.52	40.39	49.57	46.52	46.40	45.98
Al_2O_3	27.76	29.97	32.42	17.18	14.61	32.32	35.40	34.19	39.30
Fe_2O_3	12.50	9.85	11.11	17.93	7.11	1.98			
Mn_3O_4	3.65	2.79	3.10		(MnO) .17				
CaO	Trace.	3.39	2.44	.41	6.06		1.59		
MgO	.15	1.19	.32	1.57	3.98	1.29	1.29	1.00	
K_2O	.01	.56	.06		3.00	4.25	4.26	1.00	
Na_2O	1.18	2.48	1.22		3.13				
"Humus"	3.32	1.97	2.81						
P_2O_5	.19	.03	.04	.11					
Ign. loss				18.86	14.67	10.30	10.70	16.89	15.27

TABLE 1.—*Chemical composition of the finest separates from certain soils*—Continued

Observer	Novak and Smolik (*29*)			Hall (*18*)	Hall and Russell (*30*)		Hendrick and Ogg (*24*)	Robinson (*33*)
Source of fine fraction	Soil from Ivanovice, Hanna	Soil from Stara Ves, Hanna	Deep clay from Rotzyly, Prague	Soils from Rothamsted Experiment Station (average of 8)	Fertile soils from southeast England (average of 5)	Less fertile soils from southeast England (average of 4)	Soil from Crabstone, Scotland	Soils from North Wales (average of 10)
Description of fine fraction	Largest particles calculated 0.1 micron	Largest particles calculated 0.1 micron	Largest particles calculated 0.1 micron	Largest particles, 2 microns	Largest particles, 2 microns	Largest particles, 2 microns	Largest particles, 2 microns	Largest particles, 2 microns
	Per cent	*Per cent*	*Per cent*	*Per cent* [1]	*Per cent*	*Per cent*	*Per cent*	*Per cent*
SiO_2	53.91	55.53	43.89	[2] 49.5+2.7	[2] 53.2−2.3	[2] 49.0−1.8	44.08	[2] 46.2+3.6
Al_2O_3	14.46	15.08	14.26	30.9+2.9	21.5+1.3	29.8−2.6	27.64	33.0+8.4
Fe_2O_3	17.68	18.97	27.75	12.2−1.7	13.2−1.4	13.1+3.1	21.81	13.2+2.8
Mn_3O_4	3.65	.97	1.71					
CaO	1.48	1.11	2.16		1.6−1.1	1.5+2.1	.58	
MgO	1.55	.37	1.53		1.0+ .6	1.0− .5	1.61	
K_2O	.49	2.31	4.38		4.9+2.3	3.4− .9	1.10	
Na_2O	1.15	.83	3.10				.96	
"Humus"	1.55	2.50						
P_2O_5	1.53	1.21	1.22		.4− .3	.7+ .9	.36	
Ign. loss								

[1] Percentages based on the ignited weight.
[2] The + or − figures show the extreme variation of a single analysis above or below average.

The fractions analyzed by the different investigators were without doubt all made up chiefly of colloidal matter, even if the upper limit of colloidal size is assumed to be somewhat smaller than that of the largest particle included in the fractions.[3] The fractions in question were therefore probably all similar, although the upper limit of size varies somewhat. The largest particles in the fractions obtained by Schloesing and by Novak and Smolik were probably considerably less than 1 micron and were in this respect more nearly like the material analyzed by the authors.

Table 1 shows that the fine soil fractions are composed essentially of silica, alumina, "combined" water, or an unduly large proportion of organic matter, and generally iron oxide. The silica content does not vary greatly and is very much the same as that of the kaolin fractions analyzed by Schloesing. The alumina varies from 14.26 to 39.30 per cent; the majority of the figures, however, being grouped around 30 per cent. Judging from these analyses alone, one would conclude that the colloidal matter of soils and certain ceramic clays (which are really soil material) is relatively constant in silica, but may vary widely in the amount of other elements present, although the alumina does not vary greatly in the majority of cases.

It is significant that, in spite of the relatively wide variations in iron, alumina, etc., shown by certain samples, the colloidal materials from the three soils of widely different textures analyzed by Puchner show but little variation in any of the major elements. It is probable that these soils were from a restricted area, and this may have considerable to do with the constancy of composition of the colloid. The relatively small variations in the composition of the fine fractions within the series of 8 soils from the Rothamsted plots, the series of 9 soils from southeastern England, and the series of 10 soils from northern Wales are further indications of the possible relation of the composition of soil colloids to conditions prevailing within restricted areas. The same point is further brought out by the small variation found by Blanck (*5*), in the fine fractions of seven soils taken near Breslau, Germany. These fine fractions contained from 60.75 to 68.31 per cent of silica and from 27.35 to 37.13 per cent of the oxides of iron and aluminum.

COMPOUNDS PRESENT

Some of the earlier investigators give evidence concerning the way the constituents in the colloidal material are combined. Schloesing (*37*) examined three fine kaolins, analyzing the fractions which settled with different velocities in distilled water to which a few drops of ammonia had been added. Taking one clay as typical, the first three fractions which settled most rapidly and which comprised over 95 per cent of the whole mass had the composition of kaolinite, $Al_2O_3.2SiO_2.2H_2O$. The sixth fraction, about 1.5 per cent of the whole, remained suspended for 37 days. The analysis of this material is given in Table 1. It was slightly higher in silica and lower in alumina and water than kaolinite, and was regarded by Schloesing as the truly colloidal part of the kaolin. From these results one would conclude that the colloidal matter iso-

[3] In the usual system of mechanical analysis aggregates of particles less than 1 micron in diameter appear as larger particles.

lated by Schloesing was not exactly of the composition of kaolinite, though it was considered by him to be a hydrous aluminum silicate.

Van Bemmelen's (*3*) studies are a distinct contribution to our ideas of the composition of soil colloids. He treated some very heavy clay soils from river bottoms in Holland and from Java with hot moderately concentrated hydrochloric acid, then the residue with hot concentrated sulphuric acid, each acid treatment being followed by an extraction with sodium hydroxide. He considered that this treatment dissolved all the colloidal matter in the soil and did not sensibly dissolve the noncolloidal material present.[4] In the hydrochloric acid-sodium hydroxide extract, which dissolved varying amounts of silica and alumina and practically all the iron, lime, and magnesia, the molecular ratio, $\frac{SiO_2}{Al_2O_3}$, varied from 1 to 5 in different soils. The sulphuric acid-sodium hydroxide treatment dissolved considerable silica, alumina, and iron, but practically nothing else, and in several series of soils the molecular ratio of the silica to alumina was very nearly 1 to 2, which is the ratio found in kaolinite. Later work, however, showed that this strict relation between the silica and alumina did not hold with all soils, though the variation was not great. Failing to find a definite ratio between the silica and alumina in these extracts, Van Bemmelen concluded that these constituents were not present as definite compounds but rather as absorption compounds of indefinite chemical composition.

Van Bemmelen was able to remove the red color from certain red soils by dilute hydrochloric acid, and from this fact he reasoned that some form of free ferric oxide was present in these soils. He also found that dilute sodium hydroxide extracted a large amount of alumina and very little silica from some very heavy tropical clays, and from this concluded that free aluminum hydroxide was a constituent of the colloidal matter in these soils.

From the experimental work just given and from a general resemblance of the adsorptive properties of soils to the adsorptive properties of artificial gels of silicic acid and the hydroxides of iron and aluminum which he prepared and studied, Van Bemmelen (*4*) concluded that the inorganic colloidal constituents of the soil were the following gelatinous materials: Free iron oxide, free silicic acid, and indefinite adsorption compounds or complexes of silica with alumina, iron oxide, and water, and small amounts of lime, magnesia, soda, and potash.

Hall (*18*) is very guarded in his statement concerning the combinations of the elements in the fine fractions. His recent statement on the subject is as follows:

> Taking a mean of a number of analyses of the clay fraction of Rothamsted soils, then if all the alumina may be supposed to be combined as kaolinite Al_2O_3, $2SiO_2$, $2H_2O$, the clay would contain 72 to 75 per cent kaolinite, 11 to 12 per cent ferric oxide, with 9 to 10 per cent silica and 4 to 6 per cent of alkalies and alkaline earths. This means that the clay contains practically no quartz particles, all the silica being in combination with the bases.

In another publication Hall and Russell (*20*) state that "the clay is clearly a complex silicate or a mixture of several, and in our soils two varieties were found"—one from highly fertile soils, "yielding

[4] This conclusion has been questioned by Stremme and Aarnio (*41*) and others.

a clay containing about 21 per cent of alumina and 51 to 54 per cent of silica"—and the second-rate soils "yield a clay containing about 30 per cent of alumina and 50 per cent of silica."

Hilgard (*22*) considered that the fine fractions of soils which he obtained by his method of mechanical analysis consisted of a "pure clay substance," humus, silicic acid, hydrated oxides of iron and aluminum, and "zeolitic hydrates." He stated that "the pure clay substance probably consists of silica and alumina in the proportion of very nearly 46 to 40,[5] the rest (14 per cent) being water of hydration." He did not give any direct experimental evidence for the existence of the different kinds of material he considered present in the finest soil fractions, except in the case of alminum hydroxide. His evidence for the existence of this compound was that by the acid digestion method of analysis a number of clay fractions of various soils from Mississippi and California showed a much larger proportion of alumina to silica than is present in kaolinite. Hilgard considered that no combination of alumina and silica in soils could be more basic than kaolinite, and therefore the excess of alumina over that required to form kaolinite was present as free aluminum hydroxide.

Blanck (*5*) concludes from the analyses of the colloidal fractions of seven soils from near Breslau, Germany, that the colloidal fraction was mainly made up of quartz particles.

Ramann (*32*), p. 27) gives a list of colloidal products resulting from the weathering of soil minerals. This list is similar to Van Bemmelen's, but includes in addition hydrous iron silicates and hydrous magnesium silicates. Ramann's list of substances and also that of Ehrenburg (*12*) are apparently based on the previous work of other investigators.

Oden (*30*) has stated that "the true soil colloids are the innumerable fragments of both weathered and unweathered minerals, crystal chips, and amorphous substances which, in a state of fine subdivision, constitute the clay."

The general ideas of ceramic chemists concerning the composition of the finest fractions in ceramic clays have been summarized by Searle (*40*) in a general review on the subject of clays. He states:

> The smallest particles which are obtained by elutriating the materials commonly known as clays are found to correspond, more or less closely, on analysis, to a composition which may be represented by the formula $Al_2O_3.2SiO_2.2H_2O$. The constancy of composition of the better qualities of white burning clays has led to the supposition that there is in all clays an essential substance—"*true clay, clayite,* or *pelinite*"—on which all clayey mixtures depend for their chief property. The existence of this "true clay" has been so often assumed that there is a wide spread impression that it really exists as a definite chemical compound though it has never been satisfactorily isolated.

In summarizing the earlier work on the inorganic composition of soil colloids, it can be said that many investigators, especially the ceramists, believed the main constituent of the finest fractions of soils and ceramic clays to be a hydrous aluminum silicate of the composition of kaolinite. Others believed the colloidal matter to be heterogeneous and considered that it contained, in addition to the

[5] This percentage composition corresponds to that of kaolinite. In a footnote Hilgard states that "there is still some discussion as to the chemical identity of colloidal clay with kaolinite, but the objections are not convincing."

hydrous aluminum silicate, free silicic acid and free hydrated oxides of iron and aluminum. A few investigators would include a considerable proportion of quartz and unaltered minerals.

Other investigators, following Van Bemmelen, considered that the main constituent of the finest fractions of soil was not a definite chemical compound, but that the silica, alumina, iron oxide, and water were present as an indefinite absorption compound, the constituents of which were held together more feebly than the constituents of definite chemical compounds.

SOILS SELECTED FOR A STUDY OF THE COLLOIDAL MATERIAL

FIELD DESCRIPTION

The soils from which the colloids were separated were selected to represent the more important soil types, with some range in texture and with as even a distribution regarding geographical location and varying conditions of soil formation as a comparatively limited number of samples would permit. Special soil formations, such as peats, mucks, and laterites, were not selected for these studies.

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1. Carrington loam. Depth, 0 to 12 inches; 1½ miles east and north of Farmer, Black Hawk County, Iowa; color, black when wet; texture, fine grained, friable, loam, plastic when wet and characteristically gummy. Under cultivation the soil works up to a good state of tilth and does not readily form clods unless worked when wet. No stones or gravel. Topography gently rolling; drainage conditions only fair.

2. Carrington loam. Depth, 15 to 36 inches. Subsoil of No. 1. This sample is dull brownish gray in color, in texture more sandy than the surface soil.

3. Cecil clay loam. Depth, 0 to 7 inches. Two miles northwest of Bethesda, Montgomery County, Md. A red clay loam. Small amount of stones and gravel present. Clods badly if worked when wet. Topography rolling and drainage good.

4. Cecil clay loam. Depth, 0 to 9 inches; 2½ miles northeast of Washington on old Danbury Road, Wilkes County, Ga. A dark-red clay loam having a surface horizon of 2 to 3 inches more sandy in texture and more friable. This soil is plastic when wet and clods easily. No mottling noticed. Topography rolling and surface drainage excellent.

5. Cecil clay loam. Depth 9 to 36 inches. Subsoil of No. 4; a dark-red sticky clay loam.

6. Chester loam. Depth, 0 to 7 inches; three-fourths mile south of West Falls Church, Fairfax County, Va. Yellowish friable loam; plastic when wet, though it does not easily clod; no pebbles, but occasional small stones of angular quartz and schist. Topography rolling and surface drainage good.

7. Chester loam. Depth, 0 to 8 inches; one-fourth mile northwest of Glenmont, Montgomery County, Md. Light-brown to grayish-yellow loam with a relatively high content of silt; friable, mellow soil which seldom clods. Topography gently rolling and drainage good.

8. Chester Loam. Depth, 8 to 32 inches. Subsoil of No. 7. This is a yellowish-brown, firm, compact but brittle clay.

9. Clarksville silt loam. Depth, 0 to 10 inches; 1½ miles northeast of Pee Dee, Christian County, Ky. A light-brown to grayish-brown, smooth, velvety silt loam, without large grains of sand, gravel, or stones. A few limestone sink holes noticed. Topography moderately rolling, with good surface drainage.

10. Clarksville silt loam. Depth 10 to 36 inches. Subsoil of No. 9. Grayish to reddish-yellow loam grading into a yellowish-red heavy silty clay loam at lower depths. Slightly mottled with gray in the lower 6 to 8 inches.

11. Crowley silt loam. Depth 0 to 15 inches. Crowley, Acadia Parish, La. Grayish brown to ashy gray. Topography flat and drainage poor. It has a very retentive subsoil.

12. Dunkirk clay loam. Depth 0 to 10 inches. McLeans, Chautauqua County N. Y. Brownish-gray, mellow, friable silty clay loam. Topography gently sloping. Drainage fair.

13. Fallon loam. Depth 0 to 12 inches. Six miles west of Fallon, Churchill County, Nev. A dark-gray to nearly black loam. Very impervious to water. Topography rolling, though the internal drainage is poor.

14. Hagerstown loam. Depth 0 to 8 inches. Two miles south of Frederick, Frederick County, Md. Brownish-yellow loam. Does not clod when worked at the proper moisture condition. The soil occupies undulating areas, which are naturally well drained.

15. Hagerstown loam. Depth 8 to 30 inches. Subsoil of No. 14. A reddish-brown, firm, but fairly friable clay.

16. Houston black clay. Surface soil, Dallas County, Tex. This is the black, waxy soil of Texas. It is exceedingly sticky and gummy.

17. Huntington loam. Depth 0 to 8 inches. One mile west of Seneca, Montgomery County, Md. A dark-brown mellow loam carrying a high percentage of silt. Sample was taken from a rather high first-bottom area above the Potomac. Does not easily clod. Breaks up into good tilth when plowed under proper moisture conditions. It is typically Huntington in color and physical characteristics, but the material is not all derived from limestone soils, being mixed with the wash from upland areas of Chester and associated soils. Surface drainage excellent.

18. Huntington loam. Depth 8 to 30 inches. Subsoil of No. 17. A light brown silty clay loam of a rather compact but friable structure.

19. Iredell clay. Depth 6 to 24 inches. Statesville, Iredell County, N .C. Brownish-yellow, heavy, plastic, waxy clay. Shrinks and cracks badly when dry. Clods badly. Topography level to undulating. Surface drainage poor to fair and internal drainage poor.

20. Lufkin clay. Depth 5 to 36 inches. Three miles west of Starkville, Oktibbeha County, Miss. Dark gray in color and waxy and puttylike in texture. Clods badly and remains cloddy throughout the growing season. Topography flat and surface and internal drainage poor.

21. Manor loam. Depth 0 to 7 inches. Two miles northeast of Wheaton, Montgomery County, Md. A very light-brown loam carrying a noticeable amount of finely divided mica scales. Topography rolling to hilly. Surface and internal drainage good. Does not clod.

22. Manor loam. Depth 7 to 20 inches. Subsoil of No. 21. Brownish-yellow, micaceous loam, with a sufficient amount of finely divided mica to give it a slick, greasy feel and a friable structure. In places the subsoil extends to a depth of 3 feet, but generally it grades into a disintegrated schist at less depths.

23. Marshall silt loam. Depth 0 to 14 inches. Two miles west of Mynard, Case County, Nebr. A dark-brown silt loam, moderately compact, but friable in structure and easily crumbled. Nearly black when wet. Slight mottlings of a dark bluish gray are faintly discernible in the lower part of the soil. It is rather plastic and sticky when wet, but dries out so quickly after rains that it permits cultivation without much clodding. Topography as a whole is rolling, but at the point where this sample was taken the surface drainage was just sufficient to carry off the excess water.

24. Marshall silt loam. Depth 14 to 36 inches. Subsoil of No. 23. Lighter in color than the soil, more compact and contains more clay. From 20 to 24 inches the subsoil passes into a light-brown or yellowish compact silty clay loam, which becomes brownish yellow at 30 to 36 inches. There is a slight mottling of grayish streaks where the color becomes pronounced brownish yellow.

25. Miami silty clay loam. Depth 0 to 10 inches. Jefferson, about 20 miles southwest of Fort Wayne, Wells County, Ind. Light grayish brown when wet. In texture a friable silty clay loam to a depth of 7 inches, below which there appears to be more clay and the soil is more plastic. If plowed when wet, considerable clodding occurs, but in conditions of normal moisture the soil works well. Topography gently sloping, with good surface drainage.

26. Miami silty clay loam. Depth 10 to 24 inches. Subsoil of No. 25. Yellowish-brown compact silty clay loam. Contains some mottling of light gray and an occasional lump of blue clay 2 to 4 inches in diameter. At 30 inches and below there is an accumulation of calcium carbonate and fragments of limestone.

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27. Norfolk fine sandy loam. Depth 0 to 8 inches. One-fourth mile south of Scottsville, Wayne County, N. C., on the Goldsboro-Wilson Highway. A gray, fine sandy loam, representative of the heavier phases of this type. This soil occupies level to undulating areas, which are only fairly well drained, and open ditches are necessary in many places.

28. Norfolk fine sandy loam. Depth 12 to 36 inches. Subsoil of No. 27. This is a yellow, firm, but friable fine sandy loam. There is a layer of pale-yellow fine sandy loam between the surface soil and the typical subsoil, but this layer was not included in the sample.

29. Ontario loam. Depth 0 to 12 inches. One mile south and one-half mile west of Pittsford, Monroe County, N. Y. A slightly grayish brown silty loam. Mixed with the silt and clay is a small percentage of the finer sand grains. The soil is mellow and loamy and does not ordinarily form clods. It contains a few small angular and rounded cobblestones which appear to be mainly quartzite, with some shale, limestone, and red sandstone. Topography moderately rolling and surface drainage good.

30. Ontario loam. Depth 12 to 30 inches. Subsoil of No. 29. A light-brown, moderately heavy clay loam, containing some silt and gritty material. Faint mottling is sometimes present.

31. Orangeburg fine sandy loam. Depth 0 to 10 inches. One and one-half miles southeast of New Hope Church, Lauderdale County, Miss. Light-gray to reddish-gray fine sandy loam containing some medium and coarse sand. The soil is only slightly coherent. Topography gently sloping to undulating and surface drainage good. Some erosion in places.

32. Orangeburg fine sandy loam. Depth 10 to 36 inches. Bright-red sandy loam, medium to fine in texture, grading into a stiff or compact sandy clay. There is no mottling apparent.

33. Sassafras silt loam. Depth 0 to 8 inches. Near Easton, Talbot County, Md. A brown silt loam, melow and friable. Topography undulating and drainage good.

34. Sassafras slit loam. Depth 8 to 22 inches. Subsoil of No. 33.

35. Sharkey clay subsoil. From Mississippi. Depth and exact locality not certain.

36. Sharkey clay. Depth 0 to 4 inches. Valley Park, Issaquena County, Miss. A mottled dark-brown and dark-drab clay. Clods badly. Topography flat. Drainage very poor.

37. Stockton clay adobe. Depth 0 to 12 inches. Stockton, San Joaquin County, Calif. A heavy dark-gray clay soil. It clods very badly. Topography flat and surface and internal drainage very poor.

38. Stockton clay adobe. Depth 0 to 38 inches. One-fourth mile north, 3 miles west of Biggs, Butte County, Calif. As above.

39. Stockton clay adobe. Depth 38 to 50 inches. Subsoil of No. 38. This is a yellow clay loam or clay material of rather gritty, fine sandy texture, somewhat mottled with lime concretions and iron stains and containing small calcareous nodules. At 50 inches the material was cemented into a calcareous hardpan.

40. Susquehanna clay. Depth 0 to 4 inches. Shubuta, Clarke County, Miss. Reddish clay underlain with mottled clay. Clods badly, Topography nearly level and generally poorly drained.

41. Susquehanna clay. Taken from a building excavation, about 4 feet deep. Takoma Park, Montgomery County, Md.

42. Vega Baja soil. Depth 0 to 12 inches. Between Vega Baja and Manati, Porto Rico. A reddish-brown, clay loam, residual limestone soil.

43. Wabash silt loam. Depth 0 to 15 inches. One mile east of Auburn, Nemaha County, Nebr. A dark-brown to almost black, heavy silt loam. Friable at the surface but clods when worked improperly. Both soil and subsoil are granular. Topography flat, with poor drainage.

44. Wabash silt loam. Depth 15 to 36 inches. Subsoil of No. 43. A bluish-gray or dark-brown somewhat mottled silty clay loam with pronounced granular structure.

45. Yolo clay. Surface soil. Los Baños, Merced County, Calif. Depth 0 to 18 inches. Brown silty clay. Very cloddy and sticky when wet. Topography smooth. This is a so-called alkali soil. The main constituent of the alkali is sodium sulphate.

CHEMICAL COMPOSITION

Chemical analyses were made of the samples of soils just described, and these analyses are given in Table 2.

The method of analysis is that sketched in a previous publication (Robinson, *34*). It is the sodium carbonate fusion method essentially as outlined by Hillebrand (*23*).

The figures given for phosphoric acid and manganese are averages of duplicates; the same is true for the sulphur, chlorine, and organic matter in about one-third of the cases. All unusual results were repeated, and if the summation was between 99.50 and 101 per cent it was considered satisfactory. This somewhat higher limit than the usual 100.75 per cent was taken, because in many seemingly good analyses of soils and of colloids high in organic matter, iron, and aluminum, the totals run high. This is probably due to a partial reduction of the ferric oxide during ignition and in some measure to the presence of ferrous iron in the soil.

TABLE 2.—*Chemical composition of soils from which colloids were extracted*

No.	Soil type	Depth	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MnO	CaO	MgO	K_2O	Na_2O
			P. ct.	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*
1	Carrington loam, Iowa	0″–12″	77.28	0.53	8.93	2.89	0.056	0.84	0.56	1.35	1.15
2	Carrington loam, Iowa	15″–36″	82.22	.40	8.78	2.54	.016	.80	.55	1.59	1.25
3	Cecil clay loam, Maryland	0″– 7″	50.59	.39	18.67	13.82	.080	4.55	3.55	.59	.11
4	Cecil clay loam, Georgia	0″– 9″	83.81	.80	7.70	2.97	.204	.28	.15	.79	.43
5	Cecil clay loam, Georgia	9″–18″	75.68	.87	12.95	4.21	.165	.43	.14	.73	.24
6	Chester loam, Virginia	0″– 7″	77.53	1.17	9.62	4.21	.133	.07	.49	1.55	.19
7	Chester loam, Maryland	0″– 8″	84.37	.98	6.97	2.28	.049	.37	.32	2.04	.74
8	Chester loam, Maryland	8″–32″	74.73	.80	13.43	4.45	.085	.33	.41	1.55	.22
9	Clarksville silt loam, Kentucky	0″–10″	81.85	1.37	7.35	2.79	.150	.29	.23	1.36	.95
10	Clarksville silt loam, Kentucky	10″–36″	77.66	.92	10.03	3.83	.129	.38	.55	1.82	1.04
14	Hagerstown loam, Maryland	0″– 8″	82.73	.63	7.30	3.03	.142	.46	.79	1.52	.36
15	Hagerstown loam, Maryland	8″–30″	72.29	.63	12.86	5.38	.040	.48	.81	2.84	.45
16	Houston black clay, Texas	0″–12″	58.29	.79	12.70	4.52	[3]	7.77	2.08	[3]	[3]
17	Huntington loam, Maryland	0″– 8″	72.62	.78	11.85	4.55	.185	.47	.72	2.20	.93
18	Huntington loam, Maryland	8″–30″	72.12	1.20	13.32	4.82	.139	.45	.69	2.30	.54
20	Lufkin clay, Mississippi	5″–36″	75.93	1.07	12.08	4.46	.023	.52	.83	.68	.73
21	Manor loam, Maryland	0″– 7″	71.94	.55	14.68	3.43	.212	.36	.89	2.88	.40
22	Manor loam, Maryland	7″–20″	67.69	.55	17.25	4.75	.075	.25	1.22	1.57	.75
23	Marshall silt loam, Nebraska	0″–14″	72.06	.67	11.18	3.66	.050	.90	.66	2.66	1.02
24	Marshall silt loam, Nebraska	14″–18″	70.22	.71	12.91	4.73	.100	1.03	1.12	2.29	1.14
25	Miami silty clay loam, Indiana	0″–10″	77.79	.91	9.74	2.68	.075	.61	.62	2.18	1.09
26	Miami silty clay loam, Indiana	10″–24″	60.36	.82	18.24	6.84	.060	1.69	2.01	2.85	1.11
27	Norfolk fine sandy loam, North Carolina	0″– 8″	90.34	.94	2.89	1.88	.001	.10	.08	.22	.04
28	Norfolk fine sandy loam, North Carolina	12″–36″	85.69	1.06	7.62	2.67	.005	.31	.07	.40	.21
29	Ontario loam, New York	0″–12″	74.92	.72	10.47	3.48	.094	1.23	.98	1.25	2.15
30	Ontario loam, New York	12″–22″	73.45	.71	10.81	6.19	.052	1.22	1.33	1.40	2.31
31	Orangeburg fine sandy loam, Mississippi	0″–10″	93.66	.50	2.57	.93	.641	.16	.06	.45	.15
32	Orangeburg fine sandy loam, Mississippi	10″–36″	87.61	.52	6.30	2.41	.266	.26	.14	.37	.35
33	Sassafras silt loam, Maryland	0″– 8″	82.88	1.09	7.49	2.25	.043	.41	.36	1.87	.90
34	Sassafras silt loam, Maryland	8″–22″	75.45	1.05	11.89	4.45	.030	.40	.55	2.06	1.09
37	Stockton clay adobe, California	0″–38″	63.52	1.21	14.34	7.98	.159	2.34	1.81	.78	1.68
38	Stockton clay adobe, California	38″–50″	62.46	.98	15.86	7.09	.097	2.46	2.84	1.24	2.51
40	Susquehanna clay, Mississippi	4″–36″	62.07	1.00	18.45	8.42	.013	.37	.67	.76	.02
42	Vega Baja clay loam, Porto Rico	0″–12″	51.32	1.16	22.92	11.71	[3]	.30	.15	[3]	[3]
43	Wabash silt loam, Nebraska	0″–15″	72.37	.58	12.23	3.35	.107	1.07	.93	2.35	1.20
44	Wabash silt loam, Nebraska	15″–36″	73.24	.62	11.89	3.58	.079	1.06	.92	2.38	1.14

[3] Not determined.

TABLE 2.—*Chemical composition of soils from which colloids were extracted*—Continued

No.	Soil type	Depth	P_2O_5	SO_3	Cl	CO_2 from carbonates	Ignition loss	H_2O 110°	Organic [1] matter	N	Quantity [2] of colloid in soil indicated by water absorption ratio
			P. ct.	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*
1	Carrington loam, Iowa	0″–12″	0.14	0.10	0.052	0.00	6.52	2.62	3.94	0.27	32.4
2	Carrington loam, Iowa	15″–36″	.06	.04	.031	.00	2.22	1.52	.71	.05	29.4
3	Cecil clay loam, Maryland	0″– 7″	.09	[3]	[3]	.00	8.11	1.96	[3]	[3]	19.3
4	Cecil clay loam, Georgia	0″– 9″	.06	.02	.020	.00	2.89	1.17	.56	.03	10.2
5	Cecil clay loam, Georgia	9″–18″	.05	.02	.037	.00	5.50	.92	1.08	.04	31.0
6	Chester loam, Virginia	0″– 7″	.09	.07	[3]	.00	4.86	1.05	1.68	------	14.3
7	Chester loam, Maryland	0″– 8″	.04	.03	.062	.00	3.09	.89	1.62	.07	8.5
8	Chester loam, Maryland	8″–32″	.15	.03	.030	.00	4.62	2.78	.78	.03	24.8
9	Clarksville silt loam, Kentucky	0″–10″	.08	.08	.040	.00	4.09	1.90	.96	.10	23.3
10	Clarksville silt loam, Kentucky	10″–36″	.27	.08	.030	.00	3.65	1.49	1.02	.04	25.5
14	Hagerstown loam, Maryland	0″– 8″	.13	.03	.025	.14	3.69	1.12	1.48	.13	16.7
15	Hagerstown loam, Maryland	8″–30″	.11	.02	.032	.00	4.36	1.85	.52	.06	32.0
16	Houston black clay, Texas	0″–12″	[3]	[3]	[3]	5.13	13.39	7.59	[3]	[3]	55.6
17	Huntington loam, Maryland	0″– 8″	.25	.08	.018	.00	6.50	1.95	3.88	.20	23.1
18	Huntington loam, Maryland	8″–30″	.14	.06	.074	.00	4.79	2.15	1.03	.20	20.8
20	Lufkin clay, Mississippi	5″–36″	.06	.03	[3]	.00	3.78	7.61	[3]	.06	------
21	Manor loam, Maryland	0″– 7″	.17	.08	.032	.00	5.00	1.24	1.68	.11	18.4
22	Manor loam, Maryland	7″–20″	.10	.09	.029	.00	5.05	1.10	1.38	.03	18.6
23	Marshall silt loam, Nebraska	0″–14″	.21	.12	.045	.00	6.94	3.21	4.10	.23	27.3
24	Marshall silt loam, Nebraska	14″–18″	.30	.06	.032	.00	5.42	6.54	1.91	.10	34.3
25	Miami silty clay loam, Indiana	0″–10″	.29	.03	.015	.00	4.15	3.24	1.65	.09	22.7
26	Miami silty clay loam, Indiana	10″–24″	.15	.03	.039	.35	5.91	6.01	1.29	.07	50.1
27	Norfolk fine sandy loam, North Carolina	0″– 8″	.02	.03	.040	.00	3.74	.88	2.40	.06	10.7
28	Norfolk fine sandy loam, North Carolina	12″–36″	.01	.06	.017	.00	3.08	1.01	.39	.04	20.5
29	Ontario loam, New York	0″–12″	.15	.09	.033	.00	4.66	2.45	2.87	.18	18.5
30	Ontario loam, New York	12″–22″	.21	.05	.040	.00	2.21	1.91	.60	.04	11.4
31	Orangeburg fine sandy loam, Mississippi	0″–10″	.03	.09	.026	.00	1.53	.57	.77	.03	6.2
32	Orangeburg fine sandy loam, Mississippi	10″–36″	.08	.03	.027	.00	2.48	1.13	.34	.03	21.5
33	Sassafras silt loam, Maryland	0″– 8″	.15	.05	.020	.00	2.97	1.44	1.45	.07	8.0
34	Sassafras silt loam, Maryland	8″–22″	.21	.02	.033	.00	3.36	2.21	.34	.03	18.9
37	Stockton clay adobe, California	0″–38″	.23	.06	.025	.03	6.43	7.74	1.05	.02	43.1
38	Stockton clay adobe, California	38″–50″	.08	.05	.020	.00	5.09	4.47	.36	.02	23.3
40	Susquehanna clay, Mississippi	4″–36″	.05	.05	[3]	.00	8.09	4.33	[3]	[3]	30.4
42	Vega Baja clay loam, Porto Rico	0″–12″	[3]	[3]	[3]	.00	12.66	[3]	3.64	[3]	57.8
43	Wabash silt loam, Nebraska	0″–15″	.14	.16	.031	.00	6.40	2.82	3.03	.15	29.8
44	Wabash silt loam, Nebraska	15″–36″	.13	.06	.034	.00	5.39	6.34	2.40	.11	32.4

[1] Calculated by multiplying the CO_2 evolved by combustion by 0.471.
[2] See Gile (17) for a discussion of the limitations of this method.
[3] Not determined.

The analyses given in Table 2 show that the soils selected vary sufficiently in the percentages of the major elements to yield colloids of varying composition, if such variation exists, and although the extremes of composition, especially in calcium carbonate, organic matter, and phosphoric acid, are not represented among the soils selected, the variations in composition ordinarily encountered are covered by these samples. The silica varies from 51.32 to 93.66 per cent, the alumina from 2.57 to 22.92 per cent, and the iron from 0.93 to 13.82 per cent. It is recognized that colloidal matter quite different in composition from that we have extracted may be separated from peats, pure white clays, and other special soil formations.

ISOLATION AND DESCRIPTION OF THE COLLOIDAL MATERIAL

The method of isolating the colloidal material[6] (from the soils above described) was as follows: A suspension containing the colloidal matter was obtained by shaking up the soil with water, generally in the proportion of 1 to 5. In some cases it was necessary to use one part of ammonia to 3,000 parts of water to aid dispersion. After settling over night, the suspension was passed through a high-power centrifuge. The colloidal material passing through the centrifuge was concentrated to the consistency of a jelly by sucking off the water through Pasteur-Chamberland filters. The excess of water was then evaporated. Prepared in this manner, the colloid was not contaminated with an appreciable concentration of soluble salts from the evaporation of a large volume of the soil solution. The filtered solution from the colloidal suspensions contained soluble matter varying from 8 to 200 parts per million.

The particles in the suspension passing through the centrifuge were practically invisible in the ordinary microscope. As examined with the ultra-microscope, the apparent size of the particles seldom exceeded 0.3 micron in diameter. The unaggregated or primary particles had a most active Brownian movement. When the colloidal material was separated from the bulk of the solution it was in the form of a stiff, very sticky gel. This dried down, with great shrinkage, to a hard, horny mass which adhered strongly to the tongue and broke with a conchoidal fracture. The color of the different colloids, in powder form, varied greatly, as shown in Table 6.

In obtaining the colloidal material for the analyses given in Table 3 only from 5 to 10 per cent of the total colloidal matter calculated to be present was extracted. It is shown in Table 5 that the samples analyzed are fairly representative of the composition of all the colloidal matter it is possible to extract with procedure followed.

In a previous bulletin (*17*) the difficulty of extracting all the colloidal material from the soil has been explained. With the methods which the writers employed they have been able to extract from certain soils only about half of the total colloidal matter estimated to be present, even when a complete extraction was the object.

It should be pointed out here that while 1 micron has been taken in previous publications as the size distinguishing a colloidal particle from a noncolloidal particle (*1*), the analyses given in Table 3, as stated in the description of the colloidal material, were made on samples consisting of particles of 0.3 micron or below in diameter. The amount of material between 0.3 micron and 1 micron is probably small; hence there would probably be little difference in the composition of fractions having 0.3 micron and 1 micron as the upper limit of particle size.

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[6] Most of the colloidal materials analyzed in this work were prepared by M. S. Anderson, of this bureau.

ULTIMATE CHEMICAL COMPOSITION OF THE COLLOIDAL MATERIAL

COMPOSITIONS OF THE COLLOIDAL MATERIALS OF DIFFERENT SOILS

The analyses of the colloidal material extracted from the soils that have been described are given in Table 3, the methods used being the same as for the soils themselves.

TABLE 3.—*Chemical analysis of colloids from various soils and subsoils*

No.	Soil type from which colloid was extracted	Depth	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MnO	CaO	MgO	K_2O	Na_2O
			P. ct.	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*
1	Carrington loam, Iowa	0″–12″	44.89	0.47	22.59	7.75	0.057	1.48	1.44	1.36	0.22
2	Carrington loam, Iowa	15″–36″	48.04	.65	25.19	8.80	.032	1.29	1.53	.89	.38
3	Cecil clay loam, Maryland	0″– 7″	36.20	.62	28.59	16.67	.080	.51	1.32	.54	.02
4	Cecil clay loam, Georgia	0″– 9″	33.95	.62	36.06	11.02	.147	.31	.40	.56	.44
5	Cecil clay loam, Georgia	9″–18″	31.84	.53	38.28	10.04	.136	.35	.23	.46	.28
6	Chester loam, Virginia	0″– 7″	34.82	1.14	27.88	15.93	.234	.17	2.86	.85	.08
7	Chester loam, Maryland	0″– 8″	39.00	.58	29.98	11.27	.083	.93	.22	1.24	.32
8	Chester loam, Maryland	8″–32″	40.03	.70	30.58	11.34	.034	.36	.78	1.14	.19
9	Clarksville silt loam, Kentucky	0″–10″	42.40	.81	26.49	10.05	.372	.62	1.22	1.76	.25
10	Clarksville silt loam, Kentucky	10″–36″	43.68	.63	27.70	11.51	.150	.48	1.39	1.65	.34
11	Crowley silt loam, Louisiana	0″–10″	46.95	.39	27.35	8.77	.020	.99	1.47	.85	.14
12	Dunkirk clay loam, New York	0″– 8″	43.02	.37	27.92	13.16	.080	.63	2.32	3.71	.79
13	Fallon loam, Nevada	0″–12″	52.57	.30	16.49	10.70	.210	2.20	5.67	1.97	1.02
14	Hagerstown loam, Maryland	0″– 8″	39.93	.55	29.02	9.45	.108	1.25	1.53	1.61	.50
15	Hagerstown loam, Maryland	8″–30″	41.63	.57	29.86	11.31	.034	.74	1.42	1.84	.11
16	Houston black clay, Texas	0″–12″	53.34	.81	20.77	7.15	(3)	5.01	1.39	(3)	(3)
17	Huntington loam, Maryland	0″– 8″	37.79	.40	27.16	11.28	.263	.79	1.30	2.67	.54
18	Huntington loam, Maryland	8″–30″	39.54	.47	26.77	13.33	.083	.54	1.32	2.67	.45
19	Iredell clay, North Carolina	6″–24″	42.58	.46	34.26	4.66	Trace	.61	1.43	.10	.39
20	Lufkin clay, Mississippi	5″–36″	55.44	.76	22.66	8.98	.019	1.85	2.03	.65	.07
21	Manor loam, Maryland	0″– 7″	38.86	.72	31.11	10.33	.112	.64	1.23	1.37	.63
22	Manor loam, Maryland	0″–20″	40.36	.70	31.20	10.29	.077	.38	1.35	1.28	.45
23	Marshall silt loam, Nebraska	0″–14″	45.93	.48	21.72	8.94	.066	1.19	2.01	2.28	.21
24	Marshall silt loam, Nebraska	14″–36″	48.18	.50	22.00	10.03	.111	1.36	1.62	2.07	.15
25	Miami silty clay loam, Indiana	0″–40″	46.37	.70	23.96	11.47	.070	.92	2.15	2.47	.40
26	Miami silty clay loam, Indiana	10″–30″	48.48	.79	24.12	10.44	.005	1.39	2.64	2.88	.86
27	Norfolk fine sandy loam, North Carolina	0″– 8″	38.25	.79	31.21	11.25	.033	.54	.53	.26	.09
28	Norfolk fine sandy loam, North Carolina	12″–36″	41.60	.71	31.10	11.28	.005	.34	.49	.46	.22
29	Ontario loam, New York	0″–12″	38.01	.38	23.30	10.84	.152	1.37	2.34	2.23	.14
30	Ontario loam, New York	12″–22″	42.40	.56	24.71	15.27	.138	1.18	2.59	2.39	.51
31	Orangeburg fine sandy loam, Mississippi	0″–10″	40.35	.54	31.04	10.11	.185	.51	.73	.81	.24
32	Orangeburg fine sandy loam, Mississippi	10″–36″	40.35	.44	33.27	10.08	.595	.45	.67	.81	.29
33	Sassafras silt loam, Maryland	0″– 8″	39.24	.63	28.64	10.19	.123	.75	1.16	1.17	.38
34	Sassafras silt loam, Maryland	8″–22″	41.14	.70	29.26	12.73	.031	.53	1.07	1.35	.42
35	Sharkey clay, Mississippi	Not certain.	50.63	.88	20.74	9.07	.060	1.92	1.80	1.96	.34
36	Sharkey clay, Mississippi	0″– 4″	51.34	.51	22.61	8.79	(3)	1.41	2.48	(3)	(3)
37	Stockton clay adobe, California	0″–12″	48.95	1.05	21.54	13.79	.040	1.47	2.16	.28	.03
38	Stockton clay adobe, California	0″–38″	49.50	1.14	22.51	10.57	.023	1.96	2.68	.26	.66
39	Stockton clay adobe, California	38″–50″	48.61	.94	22.23	10.13	.063	1.70	3.37	.78	.50
40	Susquehanna clay, Mississippi	0″– 4″	36.97	.50	36.91	10.44	.300	.20	.42	2.12	.26
41	Susquehanna clay, Maryland	5′ – 6′	43.71	1.04	28.44	10.72	.050	.24	2.56	.86	.78
42	Vega Baja clay loam, Porto Rico	0″–12″	36.26	.65	32.85	12.44	.160	.44	.18	.36	.47
43	Wabash silt loam, Nebraska	0″–15″	51.28	.49	20.28	9.75	.052	2.19	2.09	1.91	.21
44	Wabash silt loam, Nebraska	15″–36″	50.55	.56	20.87	9.57	.033	1.59	2.21	1.97	.14
45	Yolo clay, California	0″–18″	46.25	.31	16.42	10.00	.100	1.46	5.64	2.54	1.36

[3] Not determined.

TABLE 3.—*Chemical analysis of celloids from various soils and subsoils*—Con.

No.	Soil type from which colloid was extracted	Depth	P_2O_5	SO_3	Cl	CO_2	Ignition loss	Combined[1] H_2O	H_2O 110°	Organic[2] matter	N
			P. ct.	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*
1	Carrington loam, Iowa	0″–12″	0.28	0.19	0.065	0.00	20.15	8.56	11.22	11.59	0.61
2	Carrington loam, Iowa	15″–36″	.14	.08	.037	.00	13.75	9.23	10.98	4.52	.20
3	Cecil clay loam, Maryland	0″– 7″	.19	(3)	(3)	------	17.24	12.61	4.33	4.63	.26
4	Cecil clay loam, Georgia	0″– 9″	.25	.06	.036	.00	16.67	14.42	3.23	2.25	.22
5	Cecil clay loam, Georgia	9″–18″	.11	.02	.023	.00	18.00	16.56	4.93	1.44	.11
6	Chester loam, Virginia	0″– 7″	.31	.07	(3)	.00	17.44	11.90	3.86	5.54	.36
7	Chester loam, Maryland	0″– 8″	.20	.09	.028	.00	15.88	11.77	3.76	4.11	.28
8	Chester loam, Maryland	8″–32″	.15	.05	.036	.00	15.25	10.26	5.90	4.99	.22
9	Clarksville silt loam, Kentucky	0″–10″	.65	.21	.045	.00	15.60	9.89	10.21	5.71	.38
10	Clarksville silt loam, Kentucky	10″–36″	.38	.09	.031	.00	12.79	10.51	8.00	2.28	.20
11	Crowley silt loam, Louisiana	0″–10″	.14	.14	(3)	(3)	13.35	10.63	1.38	2.72	.34
12	Dunkirk clay loam, New York	0″– 8″	.46	.08	(3)	.00	7.52	5.02	8.16	2.50	.30
13	Fallon loam, Nevada	0″–12″	.26	.11	(3)	(3)	8.87	7.04	11.78	1.83	.09
14	Hagerstown loam, Maryland	0″– 8″	.30	.11	.033	.00	16.91	9.94	3.69	6.97	.24
15	Hagerstown loam, Maryland	8″–30″	.20	.07	.032	.00	13.20	10.51	4.16	2.69	.10
16	Houston black clay, Texas	0″–12″	(3)	(3)	(3)	.00	11.44	9.60	9.16	1.84	.09
17	Huntington loam, Maryland	0″– 8″	.64	.27	.033	.00	17.96	8.14	5.33	9.82	.55
18	Huntington loam, Maryland	8″–30″	.35	.08	.032	.00	14.35	8.24	4.89	6.11	.20
19	Iredell clay, North Carolina	6″–24″	.50	Trace	(3)	.00	14.47	13.58	3.98	.89	(3)
20	Lufkin clay, Mississippi	5″–36″	.09	.02	(3)	.00	7.77	7.06	13.45	.71	.07
21	Manor loam, Maryland	0″– 7″	.28	.09	.029	.00	15.63	11.94	4.63	3.69	.21
22	Manor loam, Maryland	0″–20″	.46	.11	.029	.00	13.91	11.35	5.34	2.56	.15
23	Marshal silt loam, Nebraska	0″–14″	.46	.21	.060	.00	16.47	7.92	7.75	8.55	.51
24	Marshal silt loam, Nebraska	14″–36″	.21	.06	.032	.00	13.28	9.32	11.00	3.96	.22
25	Miami silty clay loam, Indiana	0″–40″	.11	.07	.047	.00	11.76	8.09	7.10	3.67	.27
26	Miami silty clay loam, Indiana	10″–30″	.21	.03	.034	.22	8.57	7.64	5.89	.93	.10
27	Norfolk fine sandy loam, North Carolina	0″– 8″	.23	.08	.047	.00	16.51	11.92	4.45	4.69	.22
28	Norfolk fine sandy loam, North Carolina	12″–36″	.26	.05	.028	.00	13.81	11.50	3.25	1.60	.25
29	Ontario loam, New York	0″–12″	.44	.37	.033	.00	20.46	3.33	9.95	17.13	.70
30	Ontario loam, New York	12″–22″	.25	.06	.028	.00	10.71	7.22	9.50	3.49	.23
31	Orangeburg fine sandy loam, Mississippi	0″–10″	.42	.10	.026	.00	14.89	10.63	4.34	4.26	.26
32	Orangeburg fine sandy loam, Mississippi	10″–36″	.17	.09	.024	.00	13.60	11.92	5.44	1.68	.25
33	Sassafras silt loam, Maryland	0″– 8″	.47	.20	.035	.00	17.29	10.97	5.44	6.32	.43
34	Sassafras silt loam, Maryland	8″–22″	.08	.07	.020	.00	14.08	12.49	5.32	1.59	.32
35	Sharkey clay, Mississippi	Not certain.	.28	.12	(3)	.00	12.28	8.81	7.91	3.47	.21
36	Sharkey clay, Mississippi	0″– 4″	(3)	(3)	(3)	(3)	10.93	7.45	9.30	3.48	.57
37	Stockton clay adobe, California	0″–12″	.25	.12	(3)	.00	11.44	9.56	11.91	1.88	.16
38	Stockton clay adobe, California	0″–38″	.06	.03	.020	.00	11.95	10.75	10.70	1.20	.05
39	Stockton clay adobe, California	38″–50″	.20	.04	.019	.00	12.51	9.69	8.76	2.82	.07
40	Susquehanna clay, Mississippi	0″– 4″	.02	Trace	(3)	.00	11.30	8.75	1.56	2.55	.14
41	Susquehanna clay, Maryland	5′ – 6′	.27	.09	(3)	.00	11.87	11.12	2.65	.75	(3)
42	Vega Baja clay loam, Porto Rico	0″–12″	.36	(3)	(3)	(3)	16.88	12.73	2.63	4.15	.31
43	Wabash silt loam, Nebraska	0″–15″	.25	.16	.037	.00	11.73	6.18	10.19	5.55	.31
44	Wabash silt loam, Nebraska	15″–36″	.24	.14	.034	.00	12.34	6.74	10.24	5.60	.27
45	Yolo clay, California	0″–18″	.49	.17	(3)	.00	15.61	13.42	7.39	2.19	.10

[1] The number given for combined water is the difference between ignition loss and organic matter.
[2] Calculated by multiplying the CO_2 evolved by combustion by .471.
[3] Not determined.

It can be seen from Table 3 that the colloidal matter of soils is composed mainly of silica, alumina, iron oxide, and combined water. There is quite a wide variation in the quantities of these constituents present, though a considerable number of the different colloids have almost a constant composition so far as these main constituents are concerned.

In the whole series silica varies between 31.84 and 55.44 per cent, alumina varies between 16.42 and 38.28 per cent, iron oxide varies between 4 66 per cent and 16.67 per cent, and combined water varies between 3.33 and 16.56 per cent.

Ten colloids, however, can be picked out which show only small variations in all four constituents: SiO, 38.25 to 41.63 per cent; Al_2O_3, 28.64 to 31.21 per cent; Fe_2O_3, 9.45 to 11.63 per cent; and

combined H_2O, 9.94 to 11.94 per cent. With two exceptions, these 10 colloids came from Maryland and North Carolina. Compared with the wide geographical range which all the soil colloids analyzed represent, this is considered a restricted area. This small variation in the composition of colloidal matter from a restricted area is the same as has been noted before in the analyses given in Table 1 by Puchner, by Hall and Russell, and by Robinson.

Soil colloids vary relatively much more in the quantities of calcium, magnesium, potassium, sodium, phosphorus, chlorine, and organic matter they contain than in the content of the main constituents. The sum of the CaO, MgO, K_2O, Na_2O, SO_3, and Cl varies from 1.78 per cent in the Norfolk fine sandy loam colloid to 11.66 per cent in the colloidal matter extracted from the Yolo clay. It seems probable that the quantity of these constituents present bears an inverse relation to the degree of leaching to which the colloids have been subjected.

Soda is present in soil colloids in comparatively small amount, being under 1 per cent in all but two cases. Potash, however, is relatively high. This is in accordance with the idea that potash is adsorbed by soils to a greater extent than soda and the fact that drainage waters contain much more soda than potash, while the quantities of these constituents present in the earth's crust are much the same.[7] It is further noted that the soil colloids analyzed are, with only one exception, higher in magnesia than lime. The difference is considerable. This also is in accordance with the composition of drainage waters, which contain about four times as much lime as magnesia, the lithosphere containing 4.86 per cent CaO and 3.74 per cent MgO.

In considering relations between the constituents of soil colloids it may be said that in general the alumina and silica vary inversely, the silica being high when the alumina is low. The iron oxide shows no consistent variation with either the silica or alumina, although high alumina and high iron oxide are frequently associated. In general, the sum of the more soluble constituents of soil colloids are high when the silica is high and low when the silica is low. The sum of the more soluble constituents and also the silica generally bear an inverse relation to the combined water. Sulphur is present in largest quantities when the organic matter is high.

Owing to these more or less regular variations, the colloids from different soils can be arranged into certain groups. The colloids high in silica and the more soluble constituents and low in alumina and combined water may be taken as one group; the colloids low in silica and soluble bases and high in alumina and combined water may be taken as another group; and the colloids intermediate between these two extremes may be taken as constituting a third group. There is no sharp distinction between these groups, and one group gradually merges into another. There are, of course, exceptions to this classification. For instance, some colloids low in silica are not especially high in alumina, and one colloid is high in silica without being especially high in soluble bases.

[7] The percentages of these elements in the lithosphere are as follows: K_2O, 2.98 per cent; and Na_2O, 3.75 per cent (Clarke, 8).

Although there is a wide variation in the composition of colloids from different soils, the colloidal matters extracted from any one soil and the corresponding subsoil are very similar in chemical composition. Most of the constituents present show but little variation. For instance, the average variation of certain constituents in both soil and subsoil colloids are as follows: SiO_2, 1.88 per cent; Al_2O_3, 0.97 per cent; Fe_2O_3, 1.12 per cent; CaO, 0.27 per cent; MgO, 0.22 per cent; and K_2O, 0.19 per cent.

While the colloids from the soil and corresponding subsoil are much alike in composition, there are certain differences which appear to be consistent throughout the series. The organic matter, nitrogen, sulphur, manganese, and phosphorus are, with very few exceptions, higher in the surface soil colloids, and the differences between the quantities of these constituents in the surface soil and subsoil colloids are comparatively large. Lime is just as consistently higher in the surface soil colloid, though the differences are not so large as in the case of the above-mentioned constituents.

Silica, alumina, and iron appear to concentrate slightly in the subsoil colloid. These small differences in concentration may be considered caused by the dilution of the mineral matter by a greater amount of organic matter in the surface soil colloids; for, if the constituents of the colloids are calculated on an inorganic basis, the figures for silica, alumina, and generally iron in the colloids of the soil and corresponding subsoil agree almost within the limits of analytical error.

DIFFERENCE IN COMPOSITION OF COLLOIDAL MATTER, WHOLE SOIL, AND COARSER PARTICLES

The general difference between the composition of the colloidal matter and the composition of the minerals making up the noncolloidal part of soils is shown in Table 4. The composition of the colloidal matter given in the first line is the average of 45 colloids given in Table 3. The average composition of the coarser mineral particles given in the second line was calculated for 35 of the soils from which colloidal matter had been extracted. In this calculation the following data were used: The composition of the whole soil (Table 2), the composition of the colloidal matter, and the quantity of the colloid in the soil,[8] as determined by the water-absorption method[9]. Another estimation of the average chemical composition of the mineral particles in soils common in the United States is given in the third line of the table. This was based on petrographic determinations[10] of the minerals in the fine sands and silt of 26 different soils and subsoils from the humid part of the United States.

[8] In this calculation it is assumed that the chemical composition of the colloidal matter which could not be extracted is the same as the composition of the extracted colloid.

[9] The absorption data are given in a former publication (*17*). While the water-absorption method is not an absolute determination of the colloidal matter in all cases, it is apparently fairly accurate.

[10] These determinations show that the fine sands and silt average 64 per cent quartz, 3.8 per cent orthoclase, 4.2 per cent muscovite, and 28 per cent other minerals. For calculating the chemical composition, the 28 per cent of other minerals was assumed to consist of equal parts of hornblende, biotite, plagioclase, and microcline (*34*).

TABLE 4.—*Average compositions of soils, colloids, and coarser mineral particles compared*

	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	K_2O	Na_2O	Combined H_2O
	P. ct.	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*
Colloidal matter	43.34	26.84	10.41	1.04	1.72	1.43	0.38	9.93
Coarser mineral particles	87.2	6.0	1.9	.5	.5	1.5	.9	.6
Mineral particles in fine sands and silt of a different series of 26 soils	83.3	7.3	1.5	2.0	1.7	2.9	.9	.4

The average composition of the coarser mineral particles are approximately alike, although they were calculated for two different series of soils by two different methods.

It may be seen from the table that the colloidal matter averages half as high in silica as the mixture of coarser mineral particles, 4 times as high in alumina, 5 times as high in iron, and about 20 times as high in combined water.

In tracing the relation between the composition of the colloid and of the corresponding soil, it should be borne in mind that the composition of the whole soil is a composite of the colloidal matter and the larger mineral particles. The extent of the difference in composition between the whole soil and the colloidal matter is, therefore, partly due to the degree of difference in composition of the colloids and minerals and partly due to the relative quantities in which these constituents are present.

By comparing Tables 2 and 3 it will be seen that the colloids are lower in silica and higher in all other constituents than the corresponding soil. The concentration of organic matter, magnesia, phosphoric acid, and sulphur in the extracted colloid is quite marked. In many cases the colloid contains over five times as high a percentage of these constituents as the soil.

It is known that surface soils are usually higher in silica (*34*, *35*) and lower in alumina and iron oxide than subsoils. This same relation holds true for the soils and subsoils of Table 2.

The difference in composition of soil and subsoil is of the same nature as the difference between coarse particles and colloidal matter. Since the colloidal matter in soil and subsoil is very similar, the general difference between the analyses of soil and subsoil can usually be accounted for merely by a difference in the quantity of colloidal matter present. As a rule, then, one would expect a marked difference in texture when there is much difference in composition between the surface soils and subsoils, and, conversely, there would be little difference in texture between the two layers when there is little difference in chemical composition. Experience bears this out. Of course there are many exceptions to this rule, such as when calcium carbonate, iron concretions, etc., are unevenly deposited in the various soil horizons.

RELATION OF SAMPLE ANALYZED TO TOTAL COLLOIDAL MATTER IN THE SOIL

The samples analyzed were only a small part of the total quantity of colloidal matter estimated to be present by adsorption methods. The question naturally arises: Is this small part representative of the whole? An attempt was made to answer this question by analyz-

ing several colloidal fractions successively extracted from a single soil. For this purpose four soils were extracted as completely as possible of their colloidal matter. The details of the extraction are given in a previous bulletin (*17*). The results of the analyses are given in Table 5.

TABLE 5.—*Composition of successively extracted fractions of colloidal material from certain soils*

No.	Source and fraction of colloidal material	Part of whole soil	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Ignition loss
		Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
18	Huntington loam, subsoil:								
	First colloidal fraction	2.10	39.15	0.51	29.62	14.11	0.51	1.33	12.73
	Second colloidal fraction	6.06	38.84	.56	28.98	14.77	.67	1.39	12.97
	Third colloidal fraction	2.13	45.81	.78	23.63	12.57	.65	1.19	12.65
	Weighted average of all fractions	10.29	40.34	.59	28.00	14.18	.63	1.36	12.95
	Fraction between 0.3 micron and 1 micron	.33	45.14	.68	29.81	9.05	.37	.94	9.71
23	Marshall silt loam, surface:								
	First colloidal fraction	.64	45.92	.45	22.48	8.95	1.23	1.67	17.45
	Second colloidal fraction	4.50	45.09	.44	22.54	9.11	1.15	1.80	17.44
	Third colloidal fraction	.97	45.98	(1)	23.08	8.00	1.26	1.92	17.21
	Fourth colloidal fraction	.90	50.28	(1)	19.61	7.38	1.21	1.60	------
	Weighted average of all fractions	7.01	45.96	.44	22.23	8.72	1.18	1.78	17.37
36	Sharkey clay:								
	First colloidal fraction	12.10	51.34	.51	22.61	8.79	1.41	2.88	10.93
	Second colloidal fraction	11.90	49.67	.55	22.73	9.32	1.40	2.47	12.46
	Third colloidal fraction	12.30	50.17	.68	19.17	8.28	1.12	2.09	13.36
	Fourth colloidal fraction	2.20	43.58	1.00	20.37	9.81	1.17	2.00	18.66
	Weighted average of all fractions	38.50	50.00	.61	21.42	8.85	1.30	2.45	12.62
42	Vega Baja, surface:								
	First colloidal fraction	16.60	36.26	.65	32.85	12.44	.44	.18	16.88
	Second colloidal fraction	12.20	35.45	.99	32.86	14.37	.42	.24	16.21
	Third colloidal fraction	1.10	35.93	.69	29.69	11.68	.26	.44	18.52
	Weighted average of all fractions	30.40	35.91	.79	32.74	13.22	.42	.21	16.66

[1] Not determined.

The fact that there is comparatively little variation in the composition of colloidal matter extracted from the same soil shows that soil colloids are very difficult to separate into fractions of different composition and that if two or more colloids are present the mixture is very intimate and hard to break up.

Although a small part of the colloid extracted from a soil appears to be fairly representative of the total colloid that it is possible to extract, we have no data showing the relation between the composition of the extracted colloid and the composition of colloidal matter that is not extracted by our methods. It is probable that the colloid not extracted would approach more nearly the composition of the last fraction of colloidal matter extracted and would therefore vary in composition from the total extractable colloid. The colloid not extracted by our methods may be as much as half of the total quantity of colloidal matter in the soil, as determined by both absorption and microscopical methods.

The colloids whose compositions are given in Table 3 were graded to about 0.3 micron as the size diameter of the largest particles. One micron has, however, been used as the dividing line between colloids and noncolloids in other investigations of the bureau (*1*, *17*). A comparison of the composition of the dispersible colloidal matter between 0.3 and 1 micron and the extracted colloid below 0.3 micron

is therefore important. We have such a comparison in the fractions extracted from the Huntington subsoil. The colloidal fraction between 0.3 and 1 micron, which is small in amount, differs from the composition of the total colloid below 0.3 micron, in being higher in silica and lower in iron oxide and ignition loss.

The different colloidal fractions from any one soil show a fair agreement, the more pronounced divergences generally occurring in the last fraction.[11] Although the last colloidal fraction may differ significantly in composition from the first,[12] the quantity of colloid in the last fraction is so small that it has little effect on the composition of the entire amount of extractable colloid. It is apparent that the first fraction has almost exactly the same composition as all the colloid it was possible to extract. For example, the differences in the silica contents of the first fraction and of the total colloid vary between 0.04 per cent for the Marshall and 1.33 per cent for the Sharkey colloid.

Since the first fraction is so closely representative of all the extractable colloid, one would expect duplicate extractions to yield colloids of the same composition. This appears to be so. The compositions of the Marshall and Huntington colloids given in Table 3 are almost identical with the first fractions of these same colloids given in Table 5, although the samples of Tables 3 and 5 were extracted at different times.

CAUSES OF VARIATION IN COMPOSITION OF THE COLLOIDAL MATERIAL

In considering the factors which may affect the composition of soil colloids it is necessary to trace briefly the process by which the colloids are formed.

The original source of the inorganic material in soil colloids is the rocks of the lithosphere. When waters first appeared on the earth all the rocks must have been of igneous origin.[13] The minerals of these rocks, being formed at high temperatures and in the absence of water, are not stable when bathed with water, as they are at most places on the surface of the earth; consequently they break down, with the formation of a solution, which generally drains into the rivers, and a soil, which contains the colloidal residues.

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[11] Blanck and Preiss (6) found that the last colloidal fractions extracted from a certain soil were higher in silica and lower in alumina than the first fractions, and considered that the last fractions contained a greater proportion of finely divided quartz. It will be noted that the last fractions of the Huntington and Marshall colloids are also higher in silica and lower in alumina. This is not true of the Sharkey colloid and only partly true of the Vega Baja colloid.

[12] The composition of the colloids given in Table 3 is probably not appreciably affected by the process of extraction, as only 5 to 15 times as much water as soil was used. However, in the extraction of successive fractions of colloids much more water was used, the ratio of water to soil varying between 200 and 2,000. Hence the last fractions of the successively extracted colloids were in contact with much more water than the first fractions of these colloids or the colloids whose analyses are given in Table 3. It will be shown that the water extracts of soils and colloids are comparatively high in lime. Soil colloids that have been treated with very large quantities of water would be expected to lose some lime through leaching. This may be the cause of the diminishing lime content of the last fractions of the Sharkey and Vega Baja colloids, which were exposed to very large quantities of water. Much smaller quantities of water were used in the Huntington and Marshall separations, and here the leaching effect of the water on the lime is not apparent.

[13] Clarke (8, p. 33, 116) estimates that the lithosphere contains 95 per cent of igneous rocks. The land surface is covered with 75 per cent sedimentary rocks and 25 per cent igneous rocks. The sedimentary rocks still contain large quantities of feldspar and perhaps other igneous minerals. In the coarser fractions of the soil, the minerals other than quartz are predominantly of igneous origin.

The difference in composition between the fresh and decomposed rock caused by the above process has received considerable attention from Merrill (*28*), Clarke (*8*), and others. Merrill found that the residues resulting from decomposition of rocks were lower in silica, lime, soda, potash, and magnesia and higher in alumina, iron, and combined water than the fresh rock. In the decomposition of rocks, then, which attends the formation of colloidal matter, more silica and monovalent and divalent bases are lost than alumina and iron. The relative quantities of constituents lost and the effect of this loss in causing a difference in composition between the fresh rock and decomposed residue are predicable from other data. Clarke gives the average composition of the dissolved matter in the river waters of North America at 8.60 per cent SiO_2, 0.64 per cent $Al_2O_3+Fe_2O_3$, 19.36 per cent CaO, 4.87 per cent MgO, 1.77 per cent K_2O, and 7.46 per cent Na_2O. The average composition of the lithosphere, according to Clarke, is 59.77 per cent SiO_2, 21.35 per cent $Al_2O_3+Fe_2O_3$, 4.86 per cent CaO, 3.74 per cent MgO, 2.98 per cent K_2O, and 3.25 per cent Na_2O. Reducing the $Al_2O_3+Fe_2O_3$ in both these compositions to unity in order to compare the proportions of constituents in the leachings with the proportions of the constituents in the lithosphere we have:

	SiO_2	$Al_2O_3+Fe_2O_3$	CaO	MgO	K_2O	Na_2O
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
Lithosphere	2.81	1.00	0.21	0.18	0.44	0.16
River water	13.4	1.00	30.3	7.81	2.72	11.7

It can be seen that in a broad general way the effect of leaching is to increase the alumina and iron oxide and to decrease the silica, lime, soda, magnesia, and potash in the leached residue of the lithosphere.

Soils and residual clays are in an advanced stage of rock decomposition. They should, then, show the effect of leaching in their compositions. It has already been pointed out that the colloidal matter is lower in silica [14] and higher in alumina and iron oxide than the whole soil, hence the colloidal matter shows the effect of the leaching and decomposition processes to a greater extent than the whole soil, which still contains some unaltered minerals.

The composition of the colloidal matter from any particular soil depends of course upon the conditions [15] under which the colloidal matter was formed and upon the conditions to which it was subsequently exposed. The inorganic colloidal matter in the soil, although a residual product of mineral composition, is subject to further alteration through interaction with soil water. It is difficult to evaluate all the complex conditions which have determined the composition of any particular soil colloid as it exists to-day. Some of these conditions may have been local and may have operated for only a relatively short time. The effects of certain conditions, probably

[14] This difference between the silica content of the whole soil and of the colloidal matter may be augmented by the segregation of nearly pure silica in the form of secondary quartz in the coarser soil particles, the source of the silica being the silicates which by decomposition form the colloids.

[15] "Conditions" is used here in a very broad sense and includes the composition of the parent material.

having an influence on the composition of the colloidal matter, are known in a general way.

The general factors influencing the composition of the colloid or of the whole soil may be summarized under the heads of parent material, topography, climate, and vegetation. The numerous effects of any factor can hardly be isolated from the effects of other factors, although in the case of any one colloid the effect of a certain factor might predominate. The effect of parent material would, as a rule, be more pronounced in the case of immature soils. Topography, with its control of drainage and movement of underground waters, would be important in special cases. The effects of vegetation on the composition of colloidal matter may be properly included under climate, since climate largely controls vegetation. The effect of climatic conditions would be superimposed upon the effects of parent material, and should, as a rule, be more evident in the older colloidal material.

The different colloidal materials, the compositions of which are given in Table 3, are from the more important agricultural types and are consequently from well-drained or fairly well-drained areas, so there should be little influence of topography on the composition of these soil colloids. It is possible, however, that in a few cases the colloidal matter has been enriched by exposure to underground waters carrying material derived from other areas. The composition of the parent material from which the colloidal material is derived is known in only a few cases, and then only approximately, since there is no assurance that the decomposed layers were of the same composition as the undecomposed layers now available for analysis. The present climate of the locations where the soils were obtained, however, is known, and it would seem that the composition of the different colloids should show some correlation with the climate. Rainfall and temperature, with the attendant control of vegetation, are the two most important climatic factors.

It has already been pointed out that in the different soil colloids silica and alumina generally vary inversely, and that the sum of the lime, soda, potash, and magnesia are usually high when the silica is high and low when the silica is low. These characteristics of the composition of different soil colloids make it possible to express the variability in chemical composition by index figures which are useful for correlation.

The molecular ratio of silica to the sum of the alumina and iron shows the relation between the major acidic and basic elements of the colloidal matter and is a useful figure to express the general composition of the various soil colloids. This ratio, given in the third column of Table 6, determines the order of the different colloids in the table. Column 4 shows the molecular ratio of the sum of the lime and soda to the alumina and iron. This ratio shows the relation of the more soluble or more readily replaceable monovalent and divalent bases to the more insoluble bases. The rainfall and temperature data for the locations where the soils were obtained, or for the nearest locality with available data, were furnished by the Weather Bureau. The colors were determined by T. D. Rice, of this bureau, by comparing the samples of colloidal matter with the soil-color standards used in the Soil Survey.

TABLE 6.—*Relation* $\frac{SiO_2}{R_2O_3}$ *ratio,* $\frac{CaO+Na_2O}{R_2O_3}$ *ratio, average annual precipitation, temperature, and color*

No.	Source and locality of colloidal matter	Mols $\frac{SiO_2}{R_2O_3}$	Mols $\frac{CaO+Na_2O}{R_2O_3}\times 100$	Average annual precipitation	Average annual temperature	Color
				Inches	°*F.*	
5	Cecil clay loam, subsoil, Georgia	1.20	0.25	49	62	Red.
4	Cecil clay loam, soil, Georgia	1.34	.30	49	62	Do.
42	Vega Baja soil, Porto Rico	1.34	.39	69	77	Yellowish red.
40	Susquehanna clay, Mississippi	1.35	.18	58	65	Brilliant red.
6	Chester loam, surface, Virginia	1.54	.13	[1] 44	[1] 55	Brown.
3	Cecil clay loam, surface, Maryland	1.55	.23	40	53	Red.
27	Norfolk fine sandy loam, surface, North Carolina.	1.67	.29	[1] 50	[1] 52	Yellowish brown.
32	Orangeburg fine sandy loam, subsoil, Mississippi.	1.71	.32	[1] 53	[1] 63	Red.
21	Manor loam, surface, Maryland	1.74	.58	40	54	Yellowish brown.
7	Chester loam, surface, Maryland	1.77	.59	[1] 43	[1] 53	Do.
8	Chester loam, subsoil, Maryland	1.79	.26	[1] 43	[1] 53	Light reddish brown.
22	Manor loam, subsoil, Maryland	1.81	.38	40	54	Yellowish brown.
31	Orangeburg fine sandy loam, soil, Mississippi.	1.83	.35	[1] 53	[1] 63	Dark brownish red.
28	Norfolk fine sandy loam, subsoil, North Carolina.	1.84	.25	[1] 50	[1] 52	Yellow.
33	Sassafras silt loam, soil, Maryland	1.85	.57	41	55	Brown.
17	Huntington loam, soil, Maryland	1.86	.62	[1] 35	[1] 53	Dark brown.
18	Huntington loam, subsoil, Maryland	1.89	.47	[1] 35	[1] 53	Light reddish brown.
34	Sassafras silt loam, subsoil, Maryland	1.89	.45	41	55	Reddish brown.
15	Hagerstown loam, subsoil, Maryland	1.89	.41	40	54	Brownish red.
14	Hagerstown loam, surface, Maryland	1.91	.89	40	54	Dark reddish brown.
19	Iredell clay, subsoil, North Carolina	1.93	.48	52	64	Light yellowish brown.
12	Dunkirk clay loam, surface, New York	1.99	.69	[1] 40	[1] 45	Yellowish olive.
30	Ontario loam, subsoil, New York	2.08	.86	[1] 34	[1] 47	Dark reddish brown.
41	Susquehanna clay, deep subsoil, Maryland.	2.10	.49	[1] 41	[1] 53	Yellowish red.
10	Clarksville silt loam, subsoil, Kentucky	2.10	.41	[1] 49	[1] 58	Reddish brown.
29	Ontario loam, surface, New York	2.13	.89	34	47	Dark grayish brown.
9	Clarksville silt loam, surface, Kentucky	2.18	.43	[1] 49	[1] 58	Dark brown.
11	Crowley silt loam, surface, Louisiana	2.40	.62	[1] 55	[1] 68	Grayish brown.
25	Miami silty clay loam, surface, Indiana	2.50	.75	[1] 37	[1] 50	Do.
2	Carrington loam, subsoil, Iowa	2.64	.96	32	47	Dark grayish brown.
26	Miami silty clay loam, subsoil, Indiana	2.66	1.29	[1] 37	[1] 50	Brown.
37	Stockton clay adobe, surface, California	2.72	.91	14	60	Dark gray.
1	Carrington loam, surface, Iowa	2.75	1.11	32	47	Black.
23	Marshall silt loam, surface, Nebraska	2.82	.93	[1] 30	[1] 51	Very dark grayish brown.
39	Stockton clay adobe, subsoil, California	2.85	1.36	[1] 28	[1] 62	Light yellowish brown.
38	Stockton clay adobe, surface, California	2.87	1.56	[1] 28	[1] 62	Grayish brown.
24	Marshall silt loam, subsoil, Nebraska	2.87	.99	[1] 30	[1] 51	Dark grayish brown.
36	Sharkey clay, surface, Mississippi	3.07	.91	[1] 54	[1] 66	Do.
43	Wabash silt loam, surface, Nebraska	3.16	1.63	34	52	Black.
35	Sharkey clay, Mississippi	3.23	1.53	[1] 54	[1] 66	Grayish brown.
20	Lufkin clay, subsoil, Mississippi	3.30	1.22	52	64	Cream.
44	Wabash silt loam, subsoil, Nebraska	3.33	1.15	34	52	Black.
45	Yolo clay, surface, California	3.43	2.11	[1] 20	[1] 58	Light yellowish brown.
16	Houston black clay, surface, Texas	3.56	3.60	38	65	Gray.
13	Fallon loam, surface, Nevada	3.82	2.44	5	51	Light gray.

[1] Rainfall and temperature data are not from exact locality where soil sample was taken but from nearest place with available records.

It can be seen from columns 3 and 4 of Table 6 that the $\frac{CaO+Na_2O}{Al_2O_3+Fe_2O_3}$ ratios generally increase as the $\frac{SiO_2}{Al_2O_3+Fe_2O_3}$ ratios increase, that is, the sum of the lime and soda in the colloidal matter follows the silica in a general way. A quantitative expression of the relation of the above ratios to one another is to be found in the coefficient of correlation (*43*). The coefficient of correlation between these two

ratios is $+0.81\pm04$[16]. This indicates a fairly close relationship, and it would appear that most of the factors affecting the silica ratio affect the lime plus soda ratio in the same direction, or that the two ratios are mutually dependent. It may be that the silica, like the lime and soda, is more easily removed[17] from the colloid than the iron and aluminum (relative to the quantities present) and that continued leaching tends to deplete the colloidal residue of silica and lime and soda; or it may be that the conditions which would determine a low silica ratio in the colloid at the time of formation would also determine a low lime plus soda ratio.

It can be seen from Table 6 that there is no relation between the silica ratio and the mean annual temperature, nor between the latter and the lime plus soda ratio. The correlation coefficients are respectively -0.22 ± 0.09 and -0.06 ± 0.10. There is, however, some relation between the two ratios and the rainfall. The correlation between the silica ratio and the rainfall is -0.58 ± 0.07, and the correlation between the lime plus soda ratio and the rainfall is -0.52 ± 0.07. There is, therefore, an undoubted, but not a close relation between the general chemical composition and the rainfall to which the colloid is at present exposed. It appears that rainfall is a far more important climatic factor than temperature in determining the chemical composition of the colloids studied.

The relation between the general chemical composition and the rainfall is probably causal. It is not possible to state whether the rainfall affects the composition of the colloidal matter chiefly by causing the formation of a colloid of a certain composition, or whether the composition is determined chiefly by the amount of leaching after the colloid has been formed[18]; for the continued action of soil solutions on the chemical composition of pure colloidal matter of soils is not known. In the consideration of leaching effects, the colloid can not be considered apart from the whole soil, and it is very probable that in the case of younger soils which still contain a higher proportion of the original minerals, the colloidal material which is now being formed is not very different in composition from that previously formed. In very mature soils, which contain few mineral particles other than quartz, there would be little effect of the soluble products of mineral decomposition on the colloid, and in such old soils the effect of continued leaching on the composition of the colloidal matter, after formation, would reach its maximum.

The fact that there is not a closer correlation between rainfall and composition of the colloid indicates that other conditions apart from rainfall cause variations in the composition of the colloidal matter. The character of the original and residual parent materials are probably important factors. The degree of correlation between rainfall and composition of any particular series of colloids would doubtless depend upon the selection of these colloids; the correlation might be much greater or less than that found in the 45 here examined. Ac-

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[16] The writers are indebted to C. L. Stewart and G. C. Haas of the Bureau of Agricultural Economics for advice in calculating the correlation coefficient.

[17] The silica may be removed in a colloidally dispersed condition as well as in true solution.

[18] Of course it is hardly to be expected that the constituents of the colloidal matter would be dissolved in the same proportions as they exist in the colloid as it is formed, and it is known that the colloid is not insoluble. It is evident that some change in composition of the colloidal matter must take place in the long ages after it is formed, but the magnitude of this change is unknown.

cording to the theory of soil development, it might be expected that the composition of the colloidal matter of more mature soils would show a closer relation to climate than younger soil colloids. There is some evidence of this here. The Houston and Sharkey soils are young in the localities in which they are now found. The colloids from these soils have considerably higher silica and lime plus soda ratios than would be expected from the present rainfall.

The effect of parent material on the chemical composition is difficult to evaluate. In certain cases the effect is no longer evident. For instance, the colloids from the Hagerstown, Sassafras, and Manor soils are much alike in composition, yet the parent materials are respectively limestone, outwash material from the Piedmont Plateau, and mica schist. On the other hand, the Houston colloid plainly shows the effect of the parent material in its high lime content. Thus it can be seen that colloids derived from calcareous formations may be high or low in lime, depending probably on the extent of decomposition of the parent material.

It is apparent from Table 6 that the general composition of the colloidal matter can in many cases be predicted from the color.[19] All greyish or black colloids have a silica ratio above 2.10 and the reddish or yellowish colloids generally have a lower ratio. Since there is a pretty good correlation between the lime plus soda ratio and the silica ratio, we would expect the lime plus soda ratio to be usually low in red and yellow colloids and high in blackish or gray colloids.

From the data given in Table 6 it is apparent that, in general, the colloidal matter developed in dry regions will be higher in silica and lime plus soda than colloids developed in humid regions. The composition of any particular colloid, however, can not be predicted with much certainty from the present rainfall. The similarity in general composition of the colloids Nos. 21, 7, 22, 28, 33, 17, 18, 34, 15, and 14 (see also Table 3), which were extracted from presumably old soils in parts of Maryland and North Carolina, where the rainfall and temperature are much alike, suggest that the colloidal matter in mature soils may be fairly constant in composition in a given climatic region. Sufficient information, however, has not been accumulated to substantiate this generalization.

COMPOUNDS PRESENT IN COLLOIDAL MATERIAL

FRAGMENTS OF SOIL-FORMING MINERALS

The ultimate chemical composition of the colloidal material has been discussed, but no evidence as to the manner in which the various consitutents are combined has been given. In this connection a common idea that the colloidal matter in soils is made up of the same minerals as the larger particles of the soil, but in a finer state of subdivision, will be considered.

It is known that the soil contains considerable quantities of such minerals as the feldspars, micas, and hornblende in particles 5 to 50 microns in diameter (silt size), and it would seem probable that such minerals would be present in fragments less than 0.3 micron in diameter. Hall (*19*, p. 41), however, from reasons advanced by

[19] It is interesting to note that the soil and corresponding colloid have the same color; the color of the colloid, however, is more intense. Hence there is some relation between the color of the soil and the chemical composition of the colloid.

geologists, states that "the physical process of weathering, abrasion by running water, can not reduce rock materials below a certain size." He considers that the diameters of the particles in the finest separates of the soil are below this minimum size and that therefore the finest soil fractions do not contain undecomposed rock-forming minerals. While this argument is against the presence of undecomposed mineral fragments in soil colloids produced by mechanical forces, there is nothing in it to disprove the presence of undecomposed soil minerals of colloidal dimensions formed by the chemical disintegration of the larger particles.

It was shown in Table 4 that the average composition of the colloidal matter is quite different from the average composition of the mixture of minerals constituting the coarser mineral particles and is different from any probable combinations of such minerals. It is therefore evident that the colloidal matter is not made up predominantly of the common soil-forming minerals. However, it might be assumed that the colloidal matter contains considerable quantities of either the mixed common soil-forming minerals or particular minerals, together with the gels of iron and aluminum oxide and some adsorbed monovalent and divalent bases. Although such an assumption is possible, judging only from the ultimate chemical composition, it leads to rather improbable conclusions.

The usual mixture of soil-forming minerals in the coarser particles of the soil contains a high proportion of quartz and therefore has a high silica content—about 84 per cent—while the colloid contains approximately half as much. It might be assumed, then, that the colloidal matter in many cases contains up to about 50 per cent of the mixed minerals as they occur in the coarser soil fractions. According to this assumption a considerable part or all of the silica of the colloidal matter would necessarily be present as a constituent of the soil-forming minerals, and the chief or only products of chemical decomposition of the parent soil minerals would be hydrous aluminum and iron oxides. This is hardly reasonable. It is much more probable that a large part of the silica in the colloid is also a decomposition product of the parent minerals and is present in the same state as the alumina and iron—either free or combined with them. If this is true, the colloidal matter could contain only a relatively small proportion of common mixtures of soil-forming minerals.

Since the feldspars and micas are frequently concentrated in the fine sand and silt fractions of the soil, it might be inferred that these particular minerals—which, like the colloid, contain comparatively low percentages of silica—make up a large proportion of the colloidal matter.[20] In a few cases the colloidal matter contains a sufficiently high total of the monovalent and divalent bases to permit the presence of approximately 45 per cent of feldspar or mica. In these cases, however, the monovalent and divalent bases are not present in the same proportions as in either the commoner feldspars or in the commoner micas, but certain mixtures of these minerals could be assumed.

[20] Biotite, hornblende, pyroxene, and garnet can not be present in appreciable quantities in soil colloids because soil colloids contain little, if any, ferrous iron. Nine colloids averaged 0.69 per cent ferrous iron by Cooke's method, and this figure is probably greater than the true content on account of the presence of organic matter.

Although it seems improbable that the colloidal material contains any large amount of the common soil-forming minerals, it is likewise improbable that the colloid should be entirely free of such material. In fact, in immature soils where there is an abundant supply of larger mineral particles other than quartz, as in certain glaciated and alluvial soils, there must be some small undecomposed particles of colloidal dimensions unless the decomposition process is instantaneous when the particle is reduced to a certain size.[21] Some of the ordinary soil minerals, such as secondary quartz and magnetite, which may be forming in the soil, would be of colloidal size in some stages of development and still possess their characteristic mineralogical properties.

It thus appears that the amount of undecomposed primary soil-forming minerals in soil colloids is generally small and probably variable, and that such particles are of a transitory character and are probably entirely lacking in very old or mature soils.

ATTEMPTED FRACTIONATION OF COLLOIDAL MATERIAL

By precipitation.—If the colloidal material consists of particles which differ from each other in physical properties or chemical composition, it would seem that some separation of the different kinds of particles could be made by fractional precipitation. For this purpose heavy dispersions of Cecil clay loam and Iredell clay colloids were evaporated to about one-fourth of the initial volume in a current of air at room temperature. By this process a large part of the colloidal matter was coagulated and fell to the bottom of the container, and a part of the colloid remained in suspension. The colloid which remained in suspension was poured off and collected on a baked-clay filter. Part of the collected suspension was analyzed and a part was again fractionated. The material remaining in suspension after the second evaporation was also analyzed. The compositions of the first and second suspended fractions agreed within the limits of analytical error with the composition of the original colloid. Therefore, no separation which affected the chemical composition was obtained by this method, and no further attempts were made to fractionate the colloids from other soils.

By freezing and thawing.—Freezing and thawing was found by Czermak (*9*) to decrease the absorptive capacity of the soil. The process of freezing and thawing was tried on two of the colloids here reported with the idea that they might be separated into simpler constituents. The freezing and thawing of the colloidal suspension, however, resulted in an almost complete coagulation. The quantity of colloidal matter remaining in suspension was so small that little could be learned of its identity, and it seemed impracticable to make a separation in this way.

Although the freezing and thawing process does not appear effective in fractionating the colloid, it probably does affect the solubility of certain constituents or the tenacity with which they are held by the colloid. For example, a sample of Cecil clay loam soil, after freezing and thawing five times, yielded a water extract containing 213 parts per million total solids compared with 180 parts per million yielded by the untreated sample; and a sample of Chester loam soil,

[21] This possibility has been pointed out by Whitney (*46*).

after freezing and thawing, gave 86 parts per million of total solids, while the untreated soil gave 76 parts per million.

By cataphoresis.—Ormandy, as reported by Briggs (*7*), considers that an "osmose machine," which is essentially a cataphoresis cell with a slowly revolving anode, will purify ceramic clays by separating part of the iron, which goes to the cathode, the purified clay being deposited on the anode. This claim that the clay can be purified by a separation of the iron has been questioned by Briggs (*7*), who points out that it is by no means certain that the iron oxide and particles of the pure clay substance will bear opposite charges in the suspension, as assumed by Ormandy. Briggs further contends that "if the iron oxide is absorbed by the kaolin the electrical treatment can not remove an appreciable amount of iron from the clay." Ormandy reports that out of 25 clays worked over by the osmose machine, 15 contained less iron after purification and 8 contained more.

This partial purification reported by Ormandy led to the belief that a separation of soil colloidal matter into simpler constituents might be made by cataphoresis. For this purpose very dilute suspensions of the colloidal matter from seven soils, Nos. 3, 6, 11, 12, 20, 37, 41, and a very pure and finely ground kaolinite were subjected to cataphoresis for several days. All the colloidal material appeared to be made up of negatively charged particles. No particle of any suspension appeared to be positively charged.

The colloidal materials tested represent a wide range of chemical composition and other properties, and it is doubtful if the other soil colloids could be fractionated by cataphoresis, since all the colloidal particles in a soil suspension appear to have the same charge.

Conclusions from attempted fractionations.—The attempts to separate the colloidal material into fractions of different compositions were unsuccessful and showed nothing concerning the constitution of the colloidal matter, except that if there are different compounds present, the mixture must be very intimate.

In order to make a physical separation of the colloidal matter into fractions of different composition, it would seem necessary that separate particles of different composition exist in the mixture to be separated. This is hardly to be expected. Certain possible components of the colloidal mixture, such as aluminum oxide and silicic acid, would doubtless bear opposite charges under the conditions of suspension and therefore coalesce to one particle in the mixture. The negative results of the attempted separations support the idea that separate particles of radically different composition do not exist in the suspension.

ACTION OF SOLVENTS ON COLLOIDAL MATERIAL

Water.—The various constituents of the colloidal matter presumably differ considerably in solubility in various solvents, as indicated by the work of Schloesing (*38*) and Van Bemmelen (*3*). It would seem that some progress might be made in evaluating different compounds that may be present by the use of certain solvents. In this connection it became of interest to see if there was a differential solubility of the constituents in water. This seems probable, for drainage waters contain relatively large amounts of calcium, sodium, potassium, magnesium, sulphur, and chlorine and relatively little

iron and aluminum. The source of this soluble matter is in the decomposition of the minerals and the leaching of colloidal matter.

The composition of soil solutions may give some indications of differential solubility of the constituents of the colloidal matter. The material in the soil solution, however, comes from several sources—that already in solution in the soil, that resulting from the decomposition of soil minerals, and that from the colloidal matter alone. Hence it is not certain what proportion of the total soluble matter found comes from the colloidal matter. The analyses of the solutions from which seven soil colloids were separated showed that the sums of the lime, soda, magnesia, and potash exceeded the sums of the silica, iron, and alumina, and that the silica content was about three to four times the sum of the iron and alumina. The solutions analyzed were in contact with the colloidal matter for a much longer time than they were in contact with the larger mineral particles of the soil, and it is probable that these solutions may more nearly represent the relative quantities of the various constituents that would be found in an extract of the colloid alone than the ordinary soil solution would. If the composition of the solution from which the colloidal matter was extracted bears a quantitative relation to the composition of a solution of the pure colloid, then there are indications that there is a differential solubility of the silica and the sum of the iron and alumina.

It seems from the above that there would be some change in the composition of the colloidal matter when subjected to the continuous action of water, as, for instance, in dialysis. Accordingly, dialysis was tried on one soil colloid. For this purpose a quantity of air-dried material equivalent to 4.8 grams of moisture-free Chester loam colloid (sample No. 6) was subjected to a dialysis covering 41 days. The sample was suspended in 1,500 cubic centimeters of water in the inner compartment of a dialyzer. The outer compartment held about 1,800 cubic centimeters. Heavy parchment paper was used for the membrane. The water in the outer compartment was replaced by fresh distilled water eight times at intervals of from 4 to 7 days, and the combined diffusate, totaling 12,630 cubic centimeters was evaporated for analysis. The analytical results are given in Table 7.

TABLE 7.—*Soluble salts separated by dialysis from Chester loam colloid*

Constituents	Quantity obtained from 4.8 grams colloid	Part of total amount present in colloid	Constituents	Quantity obtained from 4.8 grams colloid	Part of total amount present in colloid
	Grams	*Per cent*		*Grams*	*Per cent*
SiO_2	0.0065	0.0039	MgO	0.0128	9.34
TiO_2	Trace.		K_2O	.0103	25.2
Al_2O_3	.0044	.0033	Na_2O	.0051	100.0
Fe_2O_3	.0044	.0058	SO_3	.0025	74.4
CaO	.0073	89.0			

The total soluble material passing through the membrane was 0.0532 grams or 1.1 per cent of the 4.807 grams of moisture-free colloid acted upon. The average concentration of the diffusate, exclusive of organic matter, nitrates, chlorides, and phosphates, was 4.21 parts per million.

The table shows that silica, iron, and alumina were dialyzed through the parchment membrane, as well as lime, magnesia, soda, potash, and sulphur. There were only small quantities of lime, soda, and sulphur in the colloid, and practically the total quantities of these constituents were extracted by the dialysis. The quantities of these elements found in the diffusate are doubtless limited by the quantities present in the colloids, and colloids containing more lime, soda, and sulphur probably would yield a greater concentration of these constituents. The data indicate that the magnesia and potash are retained with considerable tenacity, although they are removed by dialysis more readily than the silica, alumina, and iron. Undoubtedly more material could be removed by a longer dialysis, and under this condition the dialyzed residue would contain little else than silica, alumina, and iron. The colloid and water used in this experiment were not sterile. Therefore the quantities of the various constituents found in the diffusate may differ from what would be found if bacterial action were eliminated.

The property of the colloidal matter of retaining the monovalent and divalent bases with considerable tenacity is further brought out by the analyses of successive fractions of colloids from the same soil. (See Table 5 and footnote 21.) Particularly large volumes of distilled water were used in extracting these colloids.

Oxalic acid.—The very pronounced red and yellow colors of some of the colloidal materials isolated suggests that some form of uncombined iron oxide might be present. It is well known that oxalic acid is one of the best solvents for iron rust, and it possesses a further advantage for diagnosing free iron oxide in soil colloids in that it is, in comparison with the common mineral acids, a weak acid and would probably have less solvent effect on the other constituents of the colloidal matter. For these reasons various soil colloids were tested with a dilute solution of oxalic acid. An amount of air-dried colloid equivalent to 2 grams of moisture-free material was shaken with distilled water till the mass appeared homogeneous. It was allowed to stand over night, and the following morning 2 grams of oxalic acid were added in solution and the volume made up to 200 cubic centimeters. After digesting on the steam bath for 1 hour the flask being shaken every 5 to 10 minutes, the solution was filtered through an acid-washed Pasteur-Chamberland filter. The silica, alumina, and iron present in the filtrate are shown in Table 8.

TABLE 8.—*Solubility of the colloidal material in 1 per cent oxalic acid*

Description of colloidal material			Fe_2O_3 dissolved		Al_2O_3 dissolved		SiO_2 dissolved	
No.	Name	Color	Part of whole colloidal material	Part of total quantity Fe_2O_3 present	Part of whole colloidal material	Part of total quantity Al_2O_3 present	Part of whole colloidal material	Part of total quantity SiO_2 present
			Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
1	Carrington loam	Black	3.81	49.2	5.47	24.3	5.34	11.9
5	Cecil clay loam	Red	6.48	64.7	9.60	24.6	2.80	8.8
20	Lufkin clay	Cream	2.43	27.0	8.84	38.5	6.79	12.3
27	Norfolk fine sandy loam	Yellowish brown	5.70	50.1	6.31	20.2	3.32	8.7
30	Ontario loam	Dark reddish brown	9.00	58.2	7.60	30.3	4.38	10.2
32	Orangeburg fine sandy loam.	Red	7.60	75.2	7.89	25.2	4.49	11.1
40	Susquehanna clay	Brilliant red	7.59	73.0	10.40	27.6	3.46	9.4
44	Wabash silt loam	Black	3.99	41.7	6.24	29.9	5.03	9.9

It can be seen from the table that the oxalic-acid treatment dissolved a large part of the iron present. Somewhat more iron was dissolved from the reddish or yellowish colloids than from the black or cream-colored colloids. The red or yellow color of the colloidal material was removed by the acid treatment.[22] The digested residue, which had lost the color characteristic of the colloid, still contained some iron, from 2.5 to 6.6 per cent, based on the original weight of the colloid. These results indicate the presence of two forms of iron in the colloid. Some form of free hydrous ferric oxide appears to be present in the red and yellow colloidal materials; a colorless form of iron, probably a silicate, appears to be present in all the colloids.

Oxalic acid, on the average, dissolved somewhat smaller quantities of silica and larger quantities of alumina than of iron. However, the silica and alumina are not dissolved in any constant proportion one to another. Therefore, the presence of a definite compound soluble in oxalic acid without change is not indicated. It can also be seen that the constituents of the colloid were not dissolved in the proportions in which they were present: about two-thirds of the iron, one-third of the alumina, and one-tenth of the silica having been brought into solution.[23]

Hydrochloric acid and sodium hydroxide.—Oxalic acid was used mainly for the purpose of detecting any form of free iron oxide that might be present in the colloidal material. Other solvents might yield suggestive results. If all the alumina and silica were present in the colloid as uncombined hydrous oxides, one would expect the alumina to be completely soluble in hydrochloric acid and the silica and alumina to be completely soluble in sodium hydroxide.[24] The action of these solvents on six soil colloids and on a colloidal suspension of kaolinite was tried.[25] The kaolinite suspension was used for purposes of comparison, since it has been generally assumed that a compound of this nature is present in soil colloids.

A quantity of the air-dried colloid equivalent to 1 gram on the moisture-free basis was shaken with water in an Erlenmeyer flask until an intimate mixture was obtained, and the mixture was allowed to stand over night. In the morning 2 grams of HCl or NaOH were added in solution and the volume made up to 200 c. c. After digesting on the steam bath for one hour and shaking every few minutes the solution was filtered through a hardened filter paper and the residue washed with very dilute HCl or NaOH. The filtrate was analyzed. The results given in Table 9 are averages of analyses made of several digestions. The results for silica, alumina,

[22] Further qualitative tests showed that all reddish colloids in the entire list of 45 lost their characteristic color when digested with oxalic acid.

[23] The partial solubility of the colloids in oxalic acid is not in harmony with O. Tamm's suggestion (*42*) that a quantitative extraction of the "gel complexes" in the soil can be made with oxalic acid or acid ammonium oxalate. In our experience the soil colloids separated by the centrifuge are only partially soluble in oxalic acid or acid ammonium oxalate, even after long digestion; further, the constituents of the colloidal material appear to be differentially dissolved. It seems doubtful that Tamm's proposed method would have quantitative significance.

[24] According to Mellor (*27*), colloidal silica can be quantitatively extracted from ceramic clays by a sodium carbonate solution, or by a mixture of sodium carbonate and sodium hydroxide.

[25] According to Dana (*10*, p. 686), kaolinite is insoluble in hydrochloric acid. This statement undoubtedly refers to comparatively coarse fragments. It is not certain, however, that kaolinite would be insoluble if the particles were of colloidal dimensions. The largest particles in the kaolinite suspension we used were about 1 micron in diameter, hence somewhat coarser than the soil colloid particles.

and iron did not agree closely, but the determinations of lime and generally of magnesia showed good agreements.

TABLE 9.—*Solubility of the colloidal material in 1 per cent HCl and 1 per cent NaOH*

No.	Description of colloidal material: Name	Color	Solubility in 1 per cent HCl: SiO_2 Part of sample	SiO_2 Part of total SiO_2	TiO_2 Part of sample	TiO_2 Part of total TiO_2	Al_2O_3 Part of sample	Al_2O_3 Part of total Al_2O_3	Fe_2O_3 Part of sample	Fe_2O_3 Part of total Fe_2O_3	CaO Part of sample	CaO Part of total CaO	MgO Part of sample	MgO Part of total MgO	P_2O_5 Part of sample	P_2O_5 Part of total P_2O_5
			Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
3	Cecil clay loam	Red	4.56	12.6	0.12	19	6.80	23.7	8.15	48.8	0.50	98	0.65	49	0.18	95
6	Chester loam	Brown	4.40	12.6	.20	18	4.82	17.2	7.16	45.0	.17	100	.45	16	.28	90
11	Crowley silt loam	Grayish brown	3.11	6.6	trace		3.54	12.9	1.68	19.1	.83	84	.42	29	.09	64
12	Dunkirk clay loam.	Yellowish olive	5.98	13.8	trace		3.99	14.3	2.49	18.8	.62	98	40	17	.27	59
20	Lufkin clay	Cream	5.98	10.8	trace		3.99	17.5	2.49	27.7	1.56	84	.40	20	.09	100
37	Stockton clay adobe.	Dark gray	5.88	12.0	trace		6.72	31.2	2.22	16.1	1.39	95	1.03	48	.07	28
	Kaolinite suspension.		.76	1.6	trace		.95	2.3								
			Solubility in 1 per cent NaOH													
3	Cecil clay loam	Red	15.39	42.5			14.62	51.1							.08	42
6	Chester loam	Brown	14.45	41.5			14.74	52.8							.18	58
11	Crowley silt loam	Grayish brown	6.11	13.0			4.67	17.0							.07	50
12	Dunkirk clay loam.	Yellowish olive	3.70	8.6			4.52	16.2							.23	50
20	Lufkin clay	Cream	6.72	12.1			4.05	17.8							.07	77
37	Stockton clay adobe.	Dark gray	4.40	9.0			1.83	8.5							.08	32
	Kaolinite suspension.		5.01	10.9			2.30	5.9								

It may be seen from the table that neither the silica nor the alumina are completely soluble in the hydrochloric acid or the sodium hydroxide used. The NaOH solution dissolved considerably more SiO_2 and Al_2O_3 from the Chester and Cecil colloids than from the others. A definite proportion of the colloidal matter is not dissolved as such in either HCl or NaOH, for the proportion of the total alumina dissolved is much greater than the proportion of the total silica dissolved. No definite ratio of silica to alumina has been dissolved, although the quantities of alumina and silica dissolved from any one colloid are generally about the same. The undissolved residues of the different colloids are not constant in composition, nor do they correspond to any definite compound of alumina and silica. In nearly every case the undissolved residue is considerably higher in silica than the untreated colloid.

The kaolinite suspension was much less soluble than the soil colloids in hydrochloric acid, but in sodium hydroxide it was about as soluble as four of the soil colloids. The silica and alumina were extracted by sodium hydroxide from the kaolinite in a ratio different from the one in which they occur in the mineral.

No definite conclusions concerning the manner in which silica and alumina are present in soil colloids can be drawn from the results of the hydrochloric acid and sodium hydroxide treatments. The results would seem to indicate that only a part of the silica and alumina, the part soluble in hydrochloric acid or sodium hydroxide, is free. The undissolved silica and alumina would seem to be combined or more insoluble than familiar forms of free SiO_2 and Al_2O_3. If all the silica and alumina were free, one would expect the proportion of Al_2O_3 to SiO_2 dissolved by HCl to differ greatly from the proportions dissolved by NaOH; but this is not the case. This consideration would point to the silica and alumina being in some combination which is less soluble than free silica and free alumina, possibly a kaolinitelike compound. On the other hand, the silica and alumina remaining undissolved do not correspond to any definite compound. The fact that the kaolinite suspension we used was less soluble in acid than the soil colloids does not prove that silica and alumina are not present as kaolinite, because the particles of the soil colloids were probably finer than the kaolinite particles and it is known that solubility depends considerably on the size of particles.

The quantity of iron oxide dissolved by the hydrochloric acid is about the same as that dissolved by oxalic acid. The only red and brown colloids in the series are those of the Cecil and Chester soils. It will be noticed that the hydrochloric acid dissolved considerably more iron from these colloids than from the four light-colored colloids. The digestion with hydrochloric acid removed the red and brown colors from the Cecil and Chester colloids just as the treatment with oxalic acid had done. The digested residues still contained large quantities of iron. This is considered further evidence that there are two forms in which iron is present in soil colloids.

Lime is practically all dissolved by dilute hydrochloric acid. Only half or considerably less of the magnesia is dissolved, however, and it would seem that the lime is held in a more easily decomposable condition than the magnesia. This same generalization is brought out by the compositions of the soil colloids as discussed on page 16 and also by the relative extractabilities in water.

The phosphoric acid in soil colloids appears to be present in a form comparatively soluble in both hydrochloric acid and sodium hydroxide.

Other concentrations of acid and alkali might be employed as partial solvents of soil colloids, though it is doubtful if any sharp, clear-cut conclusions could be drawn from the results. It has frequently been assumed that the ordinary acid-digestion method of analysis dissolves the colloidal matter in soils. The work with Sharkey and Cecil colloids showed that only about half was dissolved. Analysis of the Sharkey residue showed that the iron had all been dissolved by the acid digestion, but the ratio of silica to alumina in the residue was the same as in the original colloid. The residue from the hydrochloric-acid digestion was treated with hot fuming sulphuric acid and then with sodium hydroxide, and there remained

an undissolved residue amounting to about 20 per cent of the original material. According to the general theory of the so-called "rational" analysis of clays, this residue would be interpreted as the quantity of quartz, feldspars, and other primary minerals present in the colloid. Mellor (*27*), however, has shown that this interpretation is not correct.

COMPOUNDS INDICATED BY STOICHIOMETRICAL CALCULATION

In the review of previous work it was pointed out that Schloesing and Hilgard considered the essential constituent of soil colloids to be a hydrous aluminum silicate of the composition of kaolinite. It is evident from the analyses given in Tables 1 and 3 that soil colloids are not all of the same composition, and so, of course, can not be a definite compound. They may, however, be mixtures of two or more different compounds. This possibility could be tested for certain compounds by assuming the presence of these compounds and seeing if the analytical figures are satisfied. This method has been used by Hall (*19*), by Atterburg (*2*), and by others. These investigators assumed the presence of a hydrous aluminum silicate of the composition of kaolinite and calculated the excesses of silica and iron oxide as quartz and ferric oxide.

In our work with oxalic and hydrochloric acids the hypothesis has been advanced that part of the iron may be present combined in some way with the silica, and in the stoichiometrical calculations which follow it is assumed that part of the iron is combined with the silica in the same proportion as in nontronite [26] ($Fe_2O_3.2SiO_2.H_2O$) when there is an excess of silica over that necessary to combine with the alumina. Nontronite is the ferric equivalent of kaolinite.

In Table 10 all the alumina or silica, as the case may be, is calculated to the kaolinite formula. When there is an excess of silica over alumina, it is combined with the iron in the proportions that occur in nontronite. When there is more than sufficient silica to satisfy the alumina and iron, it is entered in the column headed "Free SiO_2," and excesses of alumina and iron oxide are treated in a similar manner. The calculated combined water is the sum of the combined water in the calculated quantities of $Al_2O_3.2SiO_2.2H_2O$, and $Fe_2O_3.2SiO_2.2H_2O$. No combined water is assigned to the excesses of silica, alumina, or iron; although if these constituents are present, some water which would not be driven off at 110° C. is probably associated with them.

[26] This is the formula given by F. W. Clark (*8*).

TABLE 10.—*Hypothetical quantities of kaolinite, montronite, silica, iron, and aluminum oxides in soil colloids*

No.	Source of colloid	Color of colloid	Kaolinite	Montronite	Excess SiO_2	Excess Al_2O_3	Excess Fe_2O_3	Combined H_2O in kaolinite and montronite	Determined combined water[1]
			Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
1	Carrington loam, Iowa	Black	57.7	15.5	11.9	0.0	0.0	9.84	8.56
2	Carrington loam, Iowa	Dark grayish brown	64.3	17.1	11.2	0.0	0.0	10.97	9.23
3	Cecil clay loam, Maryland	Red	73.0	5.0	0.0	0.0	14.2	10.74	12.61
4	Cecil clay loam, Georgia	Red	72.2	None.	0.0	8.3	11.0	9.96	14.42
5	Cecil clay loam, Georgia	Red	67.7	None.	0.0	11.8	10.0	9.34	16.56
6	Chester loam, Virginia	Brown	71.2	3.6	0.0	0.0	14.1	10.26	11.90
7	Chester loam, Maryland	Yellowish brown	76.4	8.1	0.0	0.0	7.2	11.55	11.77
8	Chester loam, Maryland	Light reddish brown	78.0	8.8	0.0	0.0	6.9	11.84	10.26
9	Clarksville silt loam, Kentucky.	Dark brown	67.6	20.7	3.1	0.0	0.0	11.78	9.89
10	Clarksville silt loam, Kentucky.	Reddish brown	70.7	25.6	1.5	0.0	0.0	12.67	10.51
11	Crowley silt loam, Louisiana	Grayish brown	69.9	17.5	7.5	0.0	0.0	11.78	10.63
12	Dunkirk clay loam, New York.	Yellowish olive	71.2	25.3	0.0	0.0	.5	12.94	5.02
13	Fallon loam, Nevada	Light gray	43.3	21.7	23.6	0.0	0.0	8.46	7.04
14	Hagerstown loam, Maryland	Dark reddish brown	74.0	13.6	0.0	0.0	2.7	11.87	9.94
15	Hagerstown loam, Maryland	Brownish red	76.3	15.6	0.0	0.0	3.6	12.62	10.51
16	Houston black clay, Texas	Gray	53.0	14.3	23.1	0.0	0.0	9.06	9.60
17	Huntington loam, Maryland	Dark brown	69.3	13.8	0.0	0.0	4.4	11.26	8.14
18	Huntington loam, Maryland	Light reddish brown	68.3	19.7	0.0	0.0	3.4	11.84	8.24
19	Iredell clay, North Carolina		87.4	3.9	0.0	0.0	2.6	12.54	13.58
20	Lufkin clay, Mississippi	Cream	57.8	17.9	21.5	0.0	0.0	10.17	7.06
21	Manor loam, Maryland	Yellowish brown	79.4	4.1	0.0	0.0	8.3	11.44	11.94
22	Manor loam, Maryland	Yellowish brown	79.6	7.8	0.0	0.0	6.4	11.93	11.35
23	Marshall silt loam, Nebraska	Very dark grayish brown.	55.4	17.8	13.2	0.0	0.0	9.82	7.92
24	Marshall silt loam, Nebraska	Dark grayish brown	56.1	20.0	14.3	0.0	0.0	10.19	9.32
25	Miami silty clay loam, Indiana.	Grayish brown	61.1	22.9	9.0	0.0	0.0	11.24	8.09
26	Miami silty clay loam, Indiana.	Brown	61.6	20.8	11.7	0.0	0.0	11.04	7.64
27	Norfolk fine sandy loam, North Carolina.	Yellowish brown	79.6	2.1	0.0	0.0	10.2	11.24	11.92
28	Norfolk fine sandy loam, North Carolina.	Yellow	77.0	12.3	0.0	0.0	5.5	12.07	11.50
29	Ontario loam, New York	Dark grayish brown	59.5	21.7	1.9	0.0	0.0	10.86	3.33
30	Ontario loam, New York	Dark reddish brown	63.1	30.5	1.3	0.0	0.0	12.43	7.22
31	Orangeburg fine sandy loam, Mississippi.	Dark brownish red	79.2	8.2	0.0	0.0	6.0	11.93	10.63
32	Orangeburg fine sandy loam, Mississippi.	Red	84.9	1.1	0.0	0.0	9.5	12.85	11.92
33	Sassafras silt loam, Maryland	Brown	73.1	13.0	0.0	0.0	3.7	11.30	10.97
34	Sassafras silt loam, Maryland	Reddish brown	74.7	16.0	0.0	0.0	4.7	12.27	12.49
35	Sharkey clay, Mississippi	Grayish brown	52.8	18.1	19.0	0.0	0.0	9.50	8.81
36	Sharkey clay, Mississippi	Dark grayish brown	57.7	17.5	17.6	0.0	0.0	10.10	7.45
37	Stockton clay adobe, California.	Dary gray	55.0	27.4	12.8	0.0	0.0	10.95	9.56
38	Stockton clay adobe, California.	Grayish brown	57.4	21.1	14.6	0.0	0.0	10.51	10.75
39	Stockton clay adobe, California.	Light yellowish brown	56.7	20.2	14.3	0.0	0.0	10.30	9.69
40	Susquehanna clay, Mississippi.	Brilliant red	78.6	None.	0.0	6.1	10.4	10.84	8.75
41	Susquehanna clay, Maryland	Yellowish red	72.6	21.4	1.5	0.0	0.0	12.63	11.12
42	Vega Baja clay loam, Porto Rico.	Yellowish red	77.1	None.	0.0	2.6	12.4	10.63	12.73
43	Wabash silt loam, Nebraska	Black	51.8	19.5	19.6	0.0	0.0	9.52	6.18
44	Wabash silt loam, Nebraska	Black	53.3	19.1	18.3	0.0	0.0	9.68	6.74
45	Yolo clay, California	Light yellowish brown	41.9	20.0	19.1	0.0	0.0	8.23	13.42

[1] This is comparable to the H_2O+ of the mineralogists. It does not include organic matter.

It can be seen from the table that soil colloids are not entirely made up of $Al_2O_3.2SiO_2.2H_2O$ and $Fe_2O_3.2SiO_2.2H_2O$; since in 31 cases the excesses of silica, alumina, and iron oxide are appreciable; that is, greater than 5 per cent, which may be allowed for additive

errors. The fact that calculations show excesses of silica, alumina, and iron oxide does not necessarily disprove the existence of the compounds assumed in the calculations. The colloidal matter may be a mixture of the compounds assumed above and free silica, alumina, and iron oxide. If the calculated excesses of silica, alumina, and iron oxide could be demonstrated, the existence of such a mixture would seem probable.

Direct proof of the presence of free silica and alumina is wanting, but the oxalic acid and hydrohloric acid treatments, together with the color of the colloids, have indicated the presence of free iron oxide in certain colloids. The colors of the colloids are in general agreement with the stoichiometrical calculations. Most of the soil colloids showing the larger excesses of ferric oxide in the calculations are distinctly red or yellow in color and most of the colloids showing a small or no excess of ferric oxide are not distinctly red or yellow. The stoichiometrical calculations on 15 colloids varying from light gray to black in color show no excesses of Fe_2O_3, and, with the exception of No. 29, these 15 colloids show an excess of silica varying from 7.6 to 23.6 per cent. Of 27 colloids which are brown to yellow or red in color, 23 show from 2.7 to 14.2 per cent of excess Fe_2O_3. There are seven colloids which are yellow to brown in color which show no excess of ferric oxide; in these, however, the excess of silica is generally small, though it reaches 19.1 per cent in the Yolo clay colloid. Only a general relation between the color and excess of ferric oxide is to be expected on account of the variation in color of pure hydrated and anhydrous ferric oxides and the presence of organic matter in the soil colloids.

There is in general a fair agreement between the combined water (that driven off above 110° C.) and the water of constitution in the calculated quantities of kaolinite and nontronite. This general agreement might be interpreted as a substantiation of the correctness of the assumptions made in the stoichiometrical calculations, since the method for determining combined water is largely empirical. In the calculations, however, no allowance is made for water combined with the excesses of SiO_2, AlO_3, and Fe_2O_3. Even without such allowance, there are 14 colloids in which the calculated water exceeds the combined water by more than 2 per cent, which is probably more than the error of the "combined" water determination in most cases. In these colloids, Nos. 10, 12, 15, 17, 18, 20, 25, 26, 29, 30, 36, 40, 43, and 44, it is certain that there can not be the quantity of the hydrated silicates assumed in the calculations. In the extreme case, that of the Ontario surface colloid, there can not be more than one-third the quantity of kaolinite and nontronite calculated. Of course, it is not certain from the combined water determination whether all or any of the so-called "combined" water is definitely water of constitution. All of the combined water may possibly be present in the same condition as in artificial inorganic gels.

The question naturally arises whether there are other compounds of silica, alumina, and water which would better fit the conditions. The assumptions of other common hydrated silicates in stoichiometrical calculations lead to no more probable conclusions than the assumption of kaolinite has done. For instance, halloysite ($Al_2O_3.2SiO_2.2H_2O$+aq.) contains the same ratio of silica to alumina as

kaolinite but would not agree with the combined water determinations any better. Allophane ($Al_2O_3.SiO_2.5H_2O$) contains more combined water than kaolinite and would show much greater excesses of silica than shown in the table. Pyrophyllite ($Al_2O_3.SiO_2.H_2O$) would take up the excess silica in all but one colloid, but practically all the iron would be shown as free iron oxide, even in those soil colloids which are grayish white in color. The application of the leverrierite[27] formula in a stoichiometrical analysis is unsatisfactory because it does not have a definite composition according to the few analyses found in the literature. The compositions of the colloids we have analyzed show but little more variation than the compositions of the minerals included in the leverrierite group.

From the considerations given above it does not seem that any of the formulæ of the commoner hydrated aluminum silicates fit the composition of soil colloids any better than the kaolinite formula.

CONCLUSIONS REGARDING COMPOUNDS PRESENT

It is not possible to draw definite conclusions as to the compounds present in the colloidal matter of soils. The constitution of colloidal minerals and of artificial silicate gels are still matters of controversy, and the "make up" of soil colloids will probably not be satisfactorily solved till more is known of the constitution of these simpler inorganic colloids. The data obtained in this work bearing on the "make up" of the colloidal matter may be summarized as follows:

(1) It is probable that there are some finely divided minerals, such as make up the larger particles of soil, in soil colloids, but the colloidal material is not chiefly made up of such particles. The quantity of finely divided minerals probably varies in different soil colloids. In general, however, it is probable that only a small part of the total colloidal matter can be made up of such material.

(2) If there are separate and distinct compounds present in the colloidal matter of soils, the mixture is very intimate and strongly resists separation. Since separate and oppositely charged colloidal particles can not form a stable suspension, it seems probable that the silica and alumina of soil colloids can not be present in separate particles, for the colloidal matter passes through the suspension stage during separation.

(3) The colloidal matter of soils resists the extraction of its constituents by solvents with considerable tenacity, and the extraction of last traces in particular is strongly resisted. Certain constituents appear to be more easily removed than others. Thus, soda and lime are more easily removed than potash and magnesia, and these last two are more easily extracted by water than silica, iron, and alumina.

(4) There are apparently two forms of iron present in soil colloids—one a hydrous ferric oxide and the other some compound without red or yellow color, presumably a silicate.

(5) Matter brought into solution by treating soil colloids with dilute alkali or acids was no more definite in composition than the original colloid. Likewise the undissolved residue was no simpler in composition.

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[27] Larsen, and Wherry (*26*) describe the properties of leverrierite and give several analyses. They give the formula $Al_2O_3.\ 2 \pm SiO_2.\ 2\frac{1}{2} \pm H_2O$. It contains small amounts of Fe_2O_3, RO, and R_4O.

(6) The stoichiometrical calculations showed that all the silica, alumina, and iron oxide in soil colloids could not be present as hydrated silicates of the composition of kaolinite and nontronite. Some suggestive relations between the color and the calculated excesses of free iron oxide in the various colloids were brought out, but on the whole the stoichiometrical calculations were not convincing enough to disprove or to establish the presence of the compounds assumed in the calculations.

The evidence presented shows that the soil colloids studied behave as very intimate mixtures and that there is little tendency to break up into compounds of definite composition. There is, however, a growing belief among colloid chemists that many colloidal substances are ultimately composed of small crystals, which are probably definite compounds. This belief, founded on theoretical considerations, has been strengthened by the identification by X-ray analysis of crystals in such pure colloids as colloidal gold, colloidal silver, silicic acid, ramie (*36*), chalcedony flint (*45*), and limonite (*25*).

With a further development of X-ray methods it may be possible to decide definitely if such complex mixtures as soil colloids are composed ultimately of crystals, and what compounds, if any, are present. It seems probable that the soil colloidal matter contains some minerals like those constituting larger soil particles, and also ferric oxide, probably hydrous. No strong evidence, however, has been obtained for the presence of other compounds.

SUMMARY

This bulletin deals with the composition of soil colloidal matter that can be brought into a finely dispersed condition in water.

Analyses are given of the colloidal matter isolated from 45 soils, which represent important agricultural types in the United States and cover wide ranges of composition, but do not include such extremes as peats and laterites.

The colloidal matter is composed mainly of silica, alumina, iron oxide, and water, with smaller amounts of lime, magnesia, potash, soda, phosphorus, manganese, sulphur, chlorine, and organic matter. There is a rather wide variation in the proportions of these constituents present in different colloids, though a considerable number of the colloids show almost a constant composition. In general, the sum of the lime, magnesia, potash, and soda is low when the silica is low and high when the silica is high. Silica and alumina usually vary inversely.

The colloidal matter from the soil and corresponding subsoil are much alike in composition.

The composition of the colloidal matter differs from that of the whole soil in being high in alumina, iron, water of combination, organic matter, magnesia, phosphorus, and sulphur and lower in silica. There is the same general difference in composition between the colloidal matter and the coarser mineral particles that there is between the colloidal matter and the soil, but the difference is more pronounced.

The part of collodial matter which is most readily dispersed is fairly representative in composition of all that it is possible to isolate by the means employed. In some cases, however, the col-

loidal matter first dispersed differs considerably from the small part that is obtained toward the end of the extraction process. No data are given on the composition of unextracted colloidal matter.

The extent of the leaching to which the colloids have been exposed is probably the most important cause of the variations in their compositions. Other factors, such as composition of the parent material, character of the leaching, and enrichment, probably produce variations also. The present rainfall is not always a reliable indication of the extent to which leaching has taken place; though, in general, soil colloids developed in humid climates show the effects of leaching to the greatest extent. Red or yellow soil colloids show the effect of more profound leaching than gray or black colloids.

The colloidal matter of soils is chiefly made up of the products of the chemical weathering of soil-forming minerals. It may, however, contain small amounts of fine mineral fragments, and some soil colloids may contain more of these mineral fragments than others.

The colloidal matter behaves as a very intimate mixture and strongly resists separation into fractions of different composition. It is probable that separate particles of different composition do not exist in the colloidal matter of soils.

The lime, soda, potash, magnesia, and silica are extracted more easily from soil colloids by water than the alumina and iron, though the colloidal matter holds all the constituents with great tenacity. Lime and soda are extracted somewhat more easily than potash and magnesia. Digestion with dilute acids removes the red or yellow colors from soil colloids. There are indications of two forms of iron in soil colloids—one a red or yellow hydrous iron oxide and the other some colorless combination, probably a silicate.

Stoichiometrical calculations show that all the silica, alumina, iron, and water in the colloidal matter are not present in the proportion to form the commoner hydrated silicates of alumina and iron, such as kaolinite and nontronite. There may, however, be some or a considerable part of the above constituents present in compounds of the composition of such minerals as kaolinite, nontronite, halloysite, or pyrophyllite. Some suggestive relations between the color and the calculated excesses of free iron oxide were brought out; but, on the whole, the calculations were not convincing enough to disprove or to establish the presence of the compounds assumed in the calculations.

LITERATURE CITED

(1) Anderson, M. S., Fry, W. H., Gile, P. L., Middleton, H. E., and Robinson, W. O.
1922. Absorption by colloidal and noncolloidal soil constituents. U. S. Dept. Agr., Bul. 1122, 20 p.

(2) Atterberg, A.
1913. Die Plasticität und Bindigkeit liefernden Bestandteile der Tone. *In* Intern. Mitt. f. Bodenkunde., v. 3, p. 291–330. 2 fig.

(3) Bemmelen, J. M. van
1904. Beiträge zur Kenntnis der Verwitterungsprodukte der Silicate in Ton—Vulkanischen und Laterit-Böden. *In* Zeit. Anorg. Allegem. Chem., v. 42, p 265–314.

(4) ————
1910. Die Absorption. 548 p., illus., Dresden.

(5) BLANCK, E.
1912. Uber die Chemische Zusammensetzung des nach der Methode Schloesing-Grandeau gewonnen Tons. *In* Jour. f. Landw., v. 60, 75–81.
(6) ———— and PRIESS, F.
1921. Bei- und Nachträge zur Kenntnis der Roterden. *In* Jour. f. Landw., v. 69, no. 2, p. 79–96.
(7) BRIGGS, T. R.
1919. Electrical endosmose. II. Industrial applications. *In* Second report on colloid chemistry and its industrial applications. British Ass. Adv. Sci., p. 39–52.
(8) CLARKE, F. W.
1920. Data of geochemistry. U. S. Dept. Int., Geol. Sur., Bul. 695, 832 p.
(9) CZERMAK, W.
1912. Ein Beitrag zur Erkenntnis der Veränderungen der sog. physikalisher Bodeneigenshaften durch Frost, Hitze und die Beigabe einiger Salze. *In* Landw. Vers. Stat., v. 76, nos. 1 and 2, p. 75–116.
(10) DANA, E. S.
1914. A system of mineralogy. 6th Ed., 1134, 75, 105 p., illus., New York.
(11) DAVIS, R. O. E.
1922. The interpretation of mechanical analysis of soils as affected by soil colloids. *In* Jour. Am. Soc. Agron., v. 14, No. 8, p. 293–298.
(12) EHRENBURG, P.
1918. Die Bodenkolloide. 3d ed., 717 p., illus., Dresden.
(13) FAILYER, G. H., SMITH J. G., and WADE. H. R.
1908. The mineral composition of soil particles. U. S. Dept. Agr., Bureau of Soils, Bul. 54, 36 p.
(14) FLETCHER, C. C., and BRYAN, H.
1912. Modification of the method of mechanical soil analysis. U. S. Dept. Agr., Bureau of Soils, Bul. 84, 16 p., 7 pl.
(15) FREUNDLICH, H.
1922. Kapillarchemie. Aufl. 2, XV, 1181 p., illus., Leipzig.
(16) FRY, W. H.
1923. The microscopic estimation of colloids in soil separates. *In* Jour. Agr. Res., v. 24, No. 10, p. 879–883.
(17) GILE, P. L., MIDDLETON, H. E., ROBINSON, W. O., FRY, W. H., and ANDERSON, M S.
1924. Estimation of colloidal material in soils by adsorption. U. S. Dept. Agr., Bul. 1193, 41 p.
(18) HALL, A. D.
1904. The mechanical analyses of soils and the composition of the fractions resulting therefrom. *In* Jour. Chem. Soc., v. 85, p. 950–963.
(19) ————.
1920. The Soil. 3d ed., 352 p., illus., London.
(20) ————, and RUSSELL, E. J.
1911. Soil surveys and soil analyses. *In* Jour. Agr. Sci., v. 4, p. 182–223.
(21) HEADDEN, W. P.
1901. A soil study. Colo. Agr. Exp. Sta., Bul. 65, 56 p.
(22) HILGARD, E. W.
1919. Soils. 593 p., illus., New York.
(23) HILLEBRAND, W. F.
1919. The analysis of silicate and carbonate rocks. U. S. Dept. Int., Geol. Sur., Bul. 700, 285 p., 23 fig.
(24) KENDRICK, J., and OGG, W. G.
1916. The composition of the soil and of the mineral particles which compose it. *In* Jour. Agr. Sci., v. 7, 458–469.
(25) KERR, P. F.
1924. The determination of opaque ore-minerals by X-ray diffraction patterns. *In* Econ. Geol., v. 19, no. 1, 1–34, 6 figs., 2 pl.
(26) LARSEN, E. S., and WHERRY, E. T.
1917. Leverrierite from Colorado. *In* Jour. Wash. Acad. Sci., v. 7, no. 8, p. 208–217.

(27) MELLOR, J. W.
1913. A treatise on quantitative inorganic analysis. 778 p., illus., 2 pl. (colored), London.
(28) MERRILL, G. P.
1906. Rocks, rock weathering, and soils. 400 p., illus., New York.
(29) NOVAK, V., and SMOLIK, L.
1923. Über die Menge und Zusammensetzung des Kolloidtones in den Boden. *In* Koll. Zeit., v. 32, no. 5, p. 338–343.
(30) ODÉN, S.
1922. On clays as disperse systems. *In* Trans. Faraday Soc., v. 17, part 2, p. 327–348, 19 fig.
(31) PUCHNER, H.
1907. Über die Verteilung von Nahrstoffen in den verschiedenen feinen Bestandteilen des Bodens. *In* Landw. Vers. Stat., v. 66, p. 463–470.
(32) RAMANN, E.
1911. Bodenkunde. 3d ed., 619 p., illus., Berlin.
(33) ROBINSON, G. W.
1917. Studies on the Paleozoic soils of North Wales. *In* Jour. Agr. Sci., v. 8, p. 338–384, 3 figs.
(34) ROBINSON, W. O.
1914. The inorganic composition of some important American soils. U. S. Dept. Agr., Bul. 122, 27 p.
(35) ————, STEINKOENIG, L. A., and FRY, W. H.
1917. Variation in the chemical composition of soils. U. S. Dept. Agr., Bul. 551, 16 p.
(36) SHERRER, P.
1920. Bestimmung der inneren Struktur und der Grösse von Kolloidteilchen mittels Röntgenstrahlen, p. 387–409, 16 fig. (*In* R. Zsigmondy, Kolloidchemie, 3d ed., 429 p., Illus., Leipzig.)
(37) SCHLOESING, TH.
1874. Sur la constitution des argiles: Kaolin. *In* Compt. rend., v. 79, p. 473–477.
(38) ————.
1901. Récherces sur l'état de l'alumine dans des terres végétales. *In* Compt. rend., v. 137, p. 1203–1212.
(39) SCHNEIDER, E. A.
1888. An analysis of a soil from Washington Territory, and some remarks on the utility of soil analyses. *In* Am. Jour. Sci., Ser. III, v. 36, p. 236–247.
(40) SEARLE, A. B.
1920. Clays and clay products. *In* Third report on colloidal chemistry and its general applications. British Ass. Adv. Sci., p. 113–154, London.
(41) STREMME, H., and AARNIO, B.
1911. Die Bestimmung des Gehaltes anorganischer Kolloid in Zersetzten Gesteinen und deren tonigen Umlagerungsprodukten. *In* Zeits. f. Prakt. Geol., v. 19, p. 329–349.
(42) TAMM, O.
1922. Eine Methode zur Bestimmung der anorganischen Komponente des Gelkomplexes in Boden. *In* Meddalenden Fran. Statens skogsförsöksanstalt., v. 19, no. 4, p. 385–404.
(43) TOLLEY, H. R., and MENDUM, S. W.
1924. A method of testing farm-management and cost-of-production data for validity of conclusions. U. S. Dept. Agr., Cir. 307, 13 p., 5 fig.
(44) TOLMAN, L. M.
1899–1901. Ann. Report Calif. Exp. Sta., p. 33–42.
(45) WASHBURN, E. W., and NAVIAS, L.
1922. The products of calcination of flint and chalcedony. *In* Jour. Am. Ceramic Soc., v. 5, no. 9, p. 565–585, 11 fig.
(46) WHITNEY, MILTON.
1921. The origin of soil colloids and the reason for the existence of this state of matters. *In* Science, new ser., v. 54, no. 409, p. 653–656.

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